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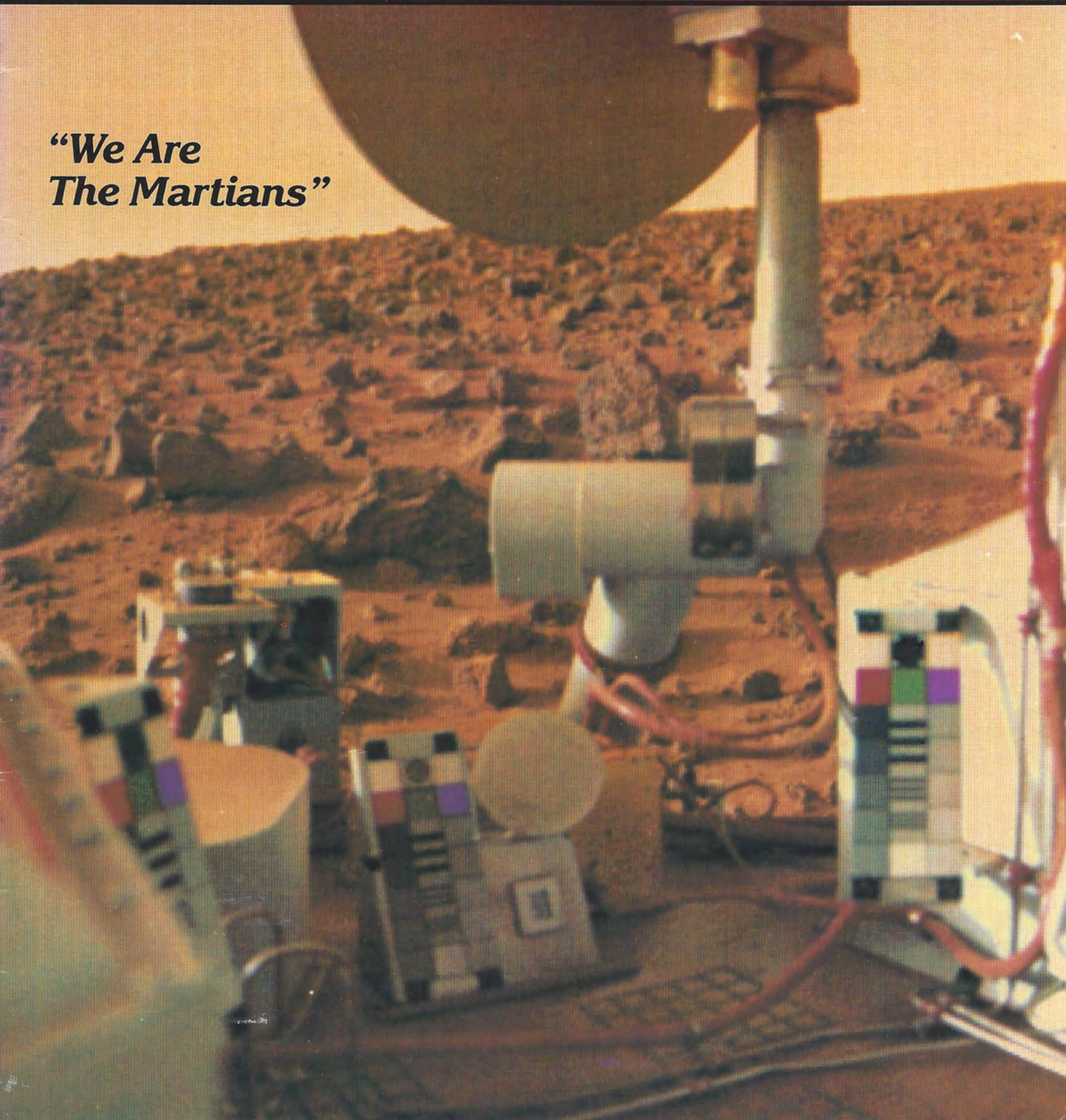

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COVER:* Viking *Lander 2 views Utopia Planitia on Mars. Spacecraft surfaces in the foreground include color targets for calibrating the transmitted images, as well as a micro-print frame bearing about ten thousand names of people involved in the project.* Viking *Lander 1, on the other side of the planet in Chryse Planitia, continues operations and has been named the Thomas A. Mutch Memorial Station in memory of the leader of the* Viking *imaging team. A commemorative plaque will be installed by the next Earth-launched expedition to visit the Lander.

PHOTO: JPL/NASA

OF WHAT IS PAST, OR PASSING, OR TO COME

an Introduction by Ray Bradbury

When I hang around books about science and scientists I break out in a rash of poetry. Same thing when I hang around the real in-the-flesh scientific movers and shakers.

Ten years ago, in my first Martian encounter with Bruce Murray, Carl Sagan, Arthur Clarke and Walter Sullivan at Caltech, I took refuge in verse. They spoke their way. I could only respond in mine.

The form of my poetry may change over the years, but the central dream is always the same. One of my earliest responses ended like this:

> Short man, large dream, I send my rockets
> forth between my ears,
> Hoping an inch of Will is worth a pound of years.
> Aching to hear a voice cry back along the
> Universal Mall:
> We've reached Alpha Centauri!
> And we're tall, O God, we're *tall!*

The dream, of course, is going-a-journey, upping the percentiles of true survival, answering the age-old question, posed so tellingly for us at the end of H. G. Wells' moving *Things To Come:*

> Which shall it be?
> The stars, or the dust of the grave?
> Choose.

I chose long ago, and wrote my choice in tales and ramshackle poetry.

Which is exactly why I am here, up front, with a brief Introduction to this mob of bright minds that follow in article after article.

I cannot speak for them, much less think for them, and I can only toss in my personal metaphors, for you to understand why scientists and technicians put up with me in the first place: they know I love them and what they do in order to build the scaffoldings of ideas and machines that will finally place us above and beyond the captive gravities of Earth.

Someone must do all the incredible thinking and building; that's their job. Someone must carry a pitifully small but bright flag, romancing any souls that might have broken from their moorings; that's mine. No use dreaming a dream if no one will build it. No use building it, if no one wants it to take off.

I nudge us in that direction by reminding us again and again:

> They have not seen the stars,
> Not one, not one,
> Of all the creatures on this world,
> In all the ages since the sands first touched
> the wind
> Not one, not one,
> No beast of all the beasts has stood
> On meadowland or plain or hill
> And known the thrill of looking at those fires
> Our soul admires what they, oh, they have never known.

(continued on page 23)

Where Next? —The Exploration of The Terrestrial Planets

by Bruce Murray, Michael C. Malin and Ronald Greeley

The completion of the *Viking* mission to Mars and of the *Pioneer* Venus probes and orbiter of Venus mark the conclusion of a great burst of American space exploration of the inner planets. New missions are being contemplated, but the level of United States activity will be at a much more modest pace for some years or decades to come. What should be the objectives of renewed United States exploration? Can we expect to gain as important new insights in the future as have characterized the remarkable pioneering space ventures of the 1960's and 1970's?

The Utility of the Moon

The Moon has a potential significance far greater than just as an object of scientific interest. From the earliest days of space exploration, the Moon has been envisioned as a potential base for manned space operations. Indeed, the establishment of large-scale automated radio-astronomy systems on the Moon, especially on the far side, seems almost a certainty. The reason is that the Moon's far side is uniquely free of interference from terrestrial radio signals that even now limit the investigation of natural radio emissions from the cosmos. Indeed, the development of satellite-to-ground transmissions for position determination, communications and other purposes is rapidly making large, virtually unexplored frequency regions of the cosmic electromagnetic radiation unobservable from Earth.

Furthermore, the Earth's ionosphere is a natural emitter of radio emissions in the kilohertz and low-megahertz region of the radio-frequency spectrum—an inevitable side effect of its use as a natural reflector for conventional AM radio signals. It simply is not possible to perform radio astronomy in these low-radio-frequency regions from the Earth's surface or even from stations orbiting the Earth. In addition, Earth-orbiting radio telescopes are vulnerable to unintentional radio-frequency interference, since the Earth's ionosphere is transparent to a large part of the electromagnetic spectrum emanating from the surface. As the terrestrial communications revolution continues, the natural cosmic radio background becomes increasingly polluted. But the far side of the Moon always faces away from the Earth and is shielded from all terrestrial radio emissions—hence its unique value as a site for celestial radio observations.

Recently, the interest in the search for evidence of extraterrestrial intelligence has begun to focus seriously on listening for microwave signals of artificial origin created by aliens living on planets orbiting other stars. Someday, when the human imagination is matched by adequate resources to carry out a full-scale radio investigation in search of alien intelligence, the far side of the Moon may well prove to be an especially precious and important environment.

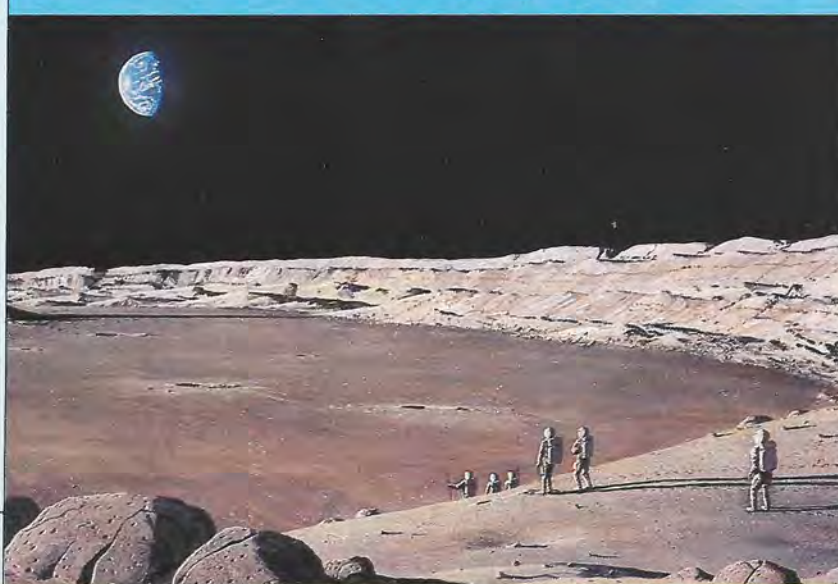
Similarly, as space transportation becomes ever cheaper and more effective, we must anticipate the utilization of lunar resources. They may be used on the Moon itself, possibly transported to Earth orbit for use there, or even brought to the Earth's surface. The initial efforts could be made within the lifetimes of our children and probably will become part of the activities of our children's children. Further scientific study of the Moon, with an eye toward identification of its resources and their utilization, provides a logical target on which to focus near-term studies. For example, the illumination of sunlight in the polar areas is nearly constant in intensity and variable merely in the azimuth, facilitating both automated and manned missions in which sunlight is easily used as a source of electrical power and heat. Similarly, frozen volatiles, if they exist on the Moon at all, may be found in permanently shaded areas at the poles. Hence, we can already suggest small regions of the Moon to explore in much greater detail (regions that were not examined in the course of the *Apollo* program because of their inaccessibility then) as leading candidates for future utilization.

On a longer time scale, the exploitation of the Moon will probably become a human endeavor. There is serious discussion by a few visionaries concerned with the creation of special self-sustaining "colonies" at gravitationally stable points of the Earth/Moon system. But in order to do this, the Moon will have to serve as both a staging base and a source of raw materials. The eventual possibility of space manufacturing, and especially the possibility of acquiring additional energy resources by means of large stations in orbit about the Earth, is no longer solely the province of science fiction writers. Serious feasibility studies are under way. As a consequence, it is plausible that at some point in the next century the Moon will become the focus of more than just scientific research for its own sake—that it will become a site of actual human activity serving practical human needs on Earth, and that its natural resources will be exploited.

Return to Mercury

Observations by orbiting satellites of Mercury's extraordinary Earthlike but miniature magnetic field could provide important information about the mysterious magnetic field of the Earth itself. Mercury is intrinsically a fickle place to explore, both because of the hostile environment arising from the intense solar radiation and, most important, because of the high speed with which a terrestrial spacecraft normally would approach the planet. It was only by substituting cleverness for chemical rocket propulsion that the *Mariner 10* mission was at all possible. A close flyby of Venus was used to perturb the trajectory toward Mercury. In addition, the resonant nature of the resulting orbit with that of Mercury was exploited to provide two additional passes by the planet. Similar cleverness probably will be required in the future to slow down a spacecraft and permit it to be captured by Mercury's gravity field so it can orbit that planet.

RETURN TO THE MOON: So far, no more than two astronauts have been on the Moon at one time. Here, on some future mission, a party of scientists descends into a major crater. This painting, by William K. Hartmann, hangs at the Lunar and Planetary Institute in Houston in memory of its former director, planetary geologist Tom McGetchin.



MERCURY: As seen by Mariner 10, *the cratered surface of Mercury seems at first glance to resemble the Moon. On closer examination, many subtle differences were found, perhaps due to the effects of the planet's relatively huge core on the cratering processes. Mercury also has large regions of chaotic topography, possibly formed by impact shock waves passing through the entire planet.*

PHOTO: JPL/NASA

What about the future? In the case of the Moon, Mars and Venus, the major step following remote-sensing missions has been the landing of an automated vehicle. Such a landing could be accomplished on Mercury later in this century. As technology was developed for the earlier missions, capabilities increased without comparable additional cost; for example, the *Viking* lander mission to Mars was by far the most sophisticated automated space mission in pursuit of the demanding goal of searching for alien microbial life there. Yet its cost (in constant dollars) was comparable to the *Surveyor* missions to the Moon twelve years earlier, when only simple mechanical and chemical tests were carried out. Hence, one or two decades from now, important measurements on the surface of Mercury should be relatively inexpensive to carry out.

The Continued Lure of Mars

Exploring Mars is expensive, and national priorities may require an extended period of time before a major new Mars initiative can be undertaken. There are still high-yield low-cost opportunities to learn more about specific locations on Mars. For example, carefully targeted "penetrators" (high-velocity surface-penetrating probes) or hard landers are possibilities. Even a Mars automated glider or airplane is being studied! All of these would probably be best delivered and supported by an orbiting vehicle that could provide further observations from orbit to refine and extend the *Viking* and *Mariner 9* data.

On a longer time scale, it seems likely that a truly autonomous, specially-designed vehicle will be developed—one capable of navigating through rocky terrain on its own, with relatively little "advice" from Earth-based engineers, and traversing thousands of kilometers. Such a system might be designed to mimic to some extent the role of a field geologist making traverses over the countryside: interesting rock samples would be collected (after being examined through the television system by Earth-based geologists), documented and placed in special containers, in the same way that the *Apollo* astronauts collected samples on the Moon. Thus, there is the potential for, and on some time scale a probability of, a golden age of geographical and geological exploration of the surface of Mars.

Sample Return from Mars

Just as the return of samples from the Moon through the *Apollo* missions was the crowning scientific achievement of the *Apollo* program, so the benchmark mission for the scientific exploration of Mars will be the return of selected samples of that planet to the Earth, where the full power of terrestrial laboratory analysis can be brought to bear. Indeed, the Soviet Union has already returned small selected samples from the Moon by totally automated means. However, samples returned from Mars involve enormously greater distances and therefore greater navigation and endurance requirements for the spacecraft, both going and returning.

One specific result of the *Viking* mission has been to greatly reduce the concern that terrestrial microbes accidentally transported to Mars might infect that planet and thereby modify, perhaps forever, any existing biota. The *Viking* discoveries of the unanticipated environmental hostility to organic compounds generally demonstrate an even greater "self-sterilizing" ability of the Martian surface than had been imagined. Additionally, the *Viking* results probably reduce, in the judgment of many, the speculative possibility that Martian soil might contain alien life forms that, if transported to Earth, could survive, reproduce in our environment, become infectious and cause "plagues." The violent reaction of the Martian soil to the mere presence of water suggests that our watery planet's environment would be highly toxic to any Martian organism. Nevertheless, the vague spectre of "back contamination" deserves and will surely receive a very full public debate when sample return missions eventually are seriously considered.

Just when such momentous steps to explore the next frontier for the human race will be carried out is uncertain. But *Viking* certainly has indicated what can be accomplished when technical skill and popular imagination are combined on such a goal.

Mars and Human Exploration

Will humans ever go to Mars? The answer must surely be "Yes." Whether it will happen by the end of this century is doubtful. It is helpful, however, to view the exploration of the solar system on a very long time scale—one that extends well beyond the lifetimes of people living today. We need to take such a view in order to better understand our role in the long human adventure of exploring the solar system. From that point of view, the manned exploration of Mars is a very important milestone in future history—one that should help us to define the more immediate goals of scientific exploration in the coming decade.

The first efforts toward landing humans on Mars will be in the nature of an adventuresome journey by astronauts or cosmonauts, as was the case with *Apollo*. It is a formidable trip, requiring much greater total propulsive capability than that for *Apollo*. There are no development programs under way by the United States or by the Soviet Union that come close in any way to having the capability for carrying out such a mission. However, the development of an automated *interplanetary shuttle* powered by low-thrust propulsion opens the possibility of a manned mission to Mars, with perhaps ten to twenty shuttle flights to the planet and back.

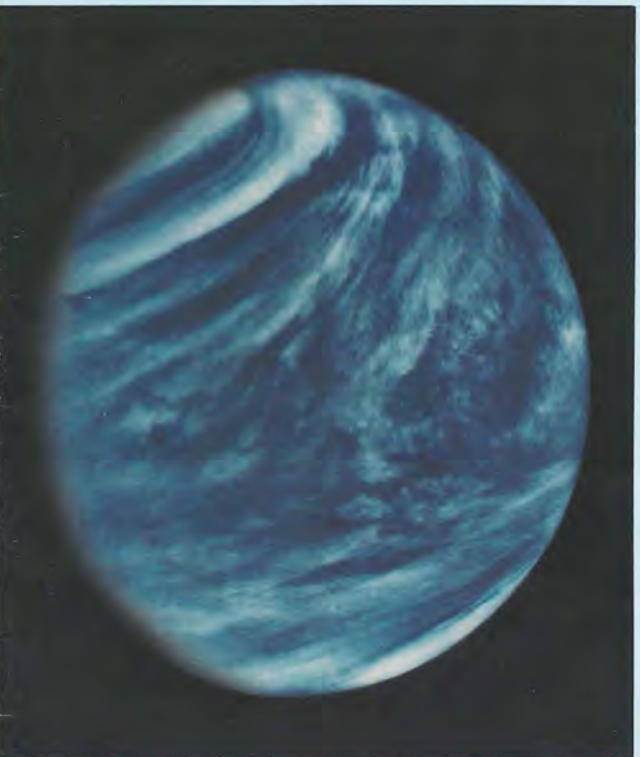
Whether humans will eventually live on Mars, either in scientific outposts or actual colonies, depends to a large extent upon two questions: 1) Can important activities be carried out more conveniently there or on the Moon or on Earth itself? 2) Can the materials necessary to human habitation be derived locally? The results of the *Viking* mission partially answer the second question, for they confirm earlier expectations of an abundance of ice and probably chemically-bound water in the surface materials. From water, oxygen can be made fairly easily. Thus, two of the most important expendables needed to sustain human operations are available locally on Mars, in addition to a rather diminished solar energy flux to provide energy. Indeed, some speculative minds have even contemplated the possibility that, at some distant future time, intentional modification of the Martian atmosphere might be undertaken in the desire to convert Mars into a more hospitable planet for human utilization (*terraforming*).

Whether terraforming ever becomes a reality or not, it does seem likely that humans will eventually reach Mars. In spite of the hostility of the Martian soil to terrestrial kinds of microbial life, the stark and lonely landscape revealed by *Viking* will one day record human tracks. *Viking* may ultimately have been a stepping stone to the existence there of very advanced forms of life—*Homo sapiens*.

THE GREAT RIFT VALLEY OF VENUS: Spacecraft instruments, piercing through Venus' enveloping clouds, have revealed a Great Rift Valley twice as long as the Grand Canyon. In this artist's conception, sulfuric acid rain and wind have sculpted the walls of the valley. PAINTING BY MICHAEL CARROLL.

The Surface of Venus

Venus remains the most exciting Earthlike planet of which we have not yet acquired an overall picture. The technical development that can make this achievement possible is not propulsion technology, but imaging radar that recently has been developed to explore the Earth, especially its oceans. Such a radar system could be operated from orbit around Venus to provide detailed maps; it would provide "pictures" of the planet's topography even through its dense clouds. The surface scale would be comparable to that which *Mariner 9* provided of Mars, with about one-kilometer resolution for most of the planet and a much higher resolution for a small percent. This would constitute a major scientific bonanza for our understanding of the nature and history of both Earth and Venus.



The circulation patterns within Venus' atmosphere were first revealed by Mariner 10 *in 1974. In this mosaic, created from photographs taken in ultraviolet light and printed in blue and white, the cloud patterns are easily distinguished.* PHOTO: JPL/NASA

Further study of the chemical and isotopic composition of the atmosphere and surface must be done to pin down the abundance of volatiles and to compare the histories of surface constituents on Venus with those of Mars and the Earth. *Pioneer* Venus mission results indicate unsuspected chemical differences between the original volatile components of Mars, Earth and Venus; we must still deal with the question of where the water went—if it ever was there. On a longer time scale, sophisticated "submarines" may provide an exciting way to explore the surface of Venus close-up, while the human observers sit comfortably at home on Earth.

And Earth?

What about the Earth itself? Are its volatiles alien or are they part of the same stuff from which the Earth was initially formed? And how about us? Are we, too, of alien origin, since we are made from those same volatiles? How did life start if, indeed, it really originated on the Earth? What is the connection, if any, between the onset of the glacial period and the development of intelligent animals from primates? The whole of human history is intimately tied to climatic change.

The polarity of our magnetic field has reversed itself many times throughout history, and at times there has been no magnetic field at all. When there is no magnetic field, there is little shielding of the Earth's surface from high-energy radiation from the Sun and the cosmos. What has been the effect of brief anomalous magnetic periods upon evolution and the development of the animals and plants of our world? Has it temporarily accelerated the number of mutations? And what really controls the concentration of minerals and ores in the Earth's crust? What else besides the colliding of tectonic plates is involved in causing the very nonuniform and extraordinary distribution of useful elements and chemicals? Answers to these and other important questions about the Earth may be obtained by studying our neighboring planets.

Over the past two decades, the exploration of our inner solar system has been an exploration back in time to the origins of our planet, to the origins of our water, to the origins of our intelligence. In the future, we can build on the brilliant beginning so that by the middle of the next century *interplanetary* geological comparison will be no more unusual than intercontinental geological comparison was by the middle of this century. We are on our way to assimilating our solar neighborhood.

Bruce Murray is Director of the Jet Propulsion Laboratory and Vice-President of The Planetary Society. Michael C. Malin and Ronald Greeley are professors in the Department of Geology and Center for Meteorite Studies at Arizona State University.

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Earth-Approaching Asteroids: Resource or Hazard?

by Brian O'Leary

This article starts with a riddle. Can you dream up a series of phenomena which can do all of the following: 1) create a ten-megaton explosion above Siberia in 1908, leveling and incinerating trees over a thousand-square-kilometer area, 2) produce darkness over the Earth 65 million years ago, causing extinctions and profound evolutionary changes in life, 3) provide the world with one-half of its nickel resources over the past two decades, 4) unlock the earliest traces of the primordial solar system, 5) become the primary potential source of materials for relieving the Earth's limits to growth in energy, food and resources?

Give up? The answer is the Earth-approaching asteroids and comets. That they could have such a pervasive effect on humanity is only now beginning to be grasped. Research, barely five years old, has proceeded along two lines; the first is increasing our understanding of the population, evolution and chemistry of objects that intersect the Earth's orbit, and the second deals with the influence they have on our everyday lives.

The story begins with the research of Eugene Shoemaker, Eleanor Helin and their colleagues at the California Institute of Technology. Using what Shoemaker describes as "practically nineteenth century science" on a shoestring NASA budget, the Cal Tech scientists have discovered a dozen Earth-approaching asteroids, bringing the total known population to fifty. Their diameters range from that of a football field (one hundred meters) to Eros, an irregular object ten to twenty kilometers across. They occupy orbits around the Sun that either intersect or closely approach the Earth's.

In their monthly trek to the Mount Palomar Observatory, Helin and her students spend four or five nights at a small, eighteen-inch Schmidt telescope photographing small patches of sky. During the twenty minutes or so that it takes for one picture, an occasional Earth-approaching asteroid betrays itself as a faint streak against a fixed background of stars, planets, galaxies, nebulae and far-away asteroids.

A second picture confirms (or disappointingly denies) the find, but the work has still not ended. The object needs to be tracked for several days or weeks to confirm its existence and establish its orbit. This usually requires alerting other astronomers at other telescopes, otherwise the find will likely fade rapidly in brightness and disappear into oblivion.

As in other fishing expeditions, the one-that-got-away happens all too often, but persistence and hard work have made Helin's efforts pay off. After the discovery of 1976AA and 1976UA (two asteroids with orbits very similar to the Earth's), 1977HB (a good candidate for a mission), and many more after that, people are listening.

Asteroids that sometimes pass inside the Earth's orbit are called Apollos, after the name given to the first one discovered in 1932 by Karl Reinmuth at the University of Heidelberg. He saw the streak of Apollo in the course of a photographic search for ordinary asteroids. Since the naming of Apollo nearly fifty years ago, the Earth-approachers have been given colorful names such as Hermes, Eros, Anteros, Belulia, Geographos, Toro, Icarus, Bacchus and, most recently, Ra-Shalom.

Palomar astronomer Charles Kowal, a regular observer at one of the world's most advanced and sensitive survey telescopes, has caught Apollo fever. Using the 48-inch Schmidt telescope, he examines his large, sharp, star-filled plates for narrow, faint streaks and blobs. As a result of this new interest, Kowal discovered the mini-planet Chiron, which inhabits the darkness between the planets Saturn and Uranus. Meanwhile, observers in West Germany, Japan, Chile and Australia are also playing the Apollo game, and Helin has become a world traveler. "It's tiring," she recently said, "but well worth the effort."

We have barely begun the search for new Earth-approachers. Shoemaker and others estimate that, over time, 100,000 asteroids with diameters greater than 100 meters pass close to the Earth. Many of these can be detected by existing telescopes.

Background: MINING AN APOLLO ASTEROID: A spacesuited man works beside a mining platform on an Earth-crossing asteroid. The long, adjustable legs on the platform are necessary to level the platform on the irregularly-shaped body. The technology to mine asteroids may be available within the next few decades. Painting by Don Dixon.

Top Left: ASTEROID IMPACT: An event of this magnitude could happen every 1.5 billion years. Here the artist pictures an asteroid 100 kilometers in diameter striking the Earth. The impact of a much smaller asteroid, only 5 kilometers in diameter, might have been responsible for the extinction of the dinosaurs 65 million years ago. Painting by Don Dixon.

Top Center: BRINGING BACK A SMALL ASTEROID: A solar-powered, electromagnetic mass driver moves a small Apollo asteroid into Earth orbit to provide materials for the construction of orbiting habitats. Painting by William K. Hartmann.

Understanding Origins

Meanwhile, there is another revolution going on in asteroid science. In recent years, Thomas McCord, Michael Gaffey, David Morrison, Dennis Matson, Lawrence Lebofsky, Carle Pieters, Glenn Veeder, Joseph Veverka, Clark Chapman, Ben Zellner and others have classified the chemical compositions of several hundred asteroids by observing how they reflect sunlight. In some cases they can make specific identifications of metals, minerals and water. The data suggest strongly that the asteroids fall into the same classes as meteorites that land on Earth. Some are stony, consisting mainly of silicon and oxygen, some are metal-rich (in extreme cases nearly one hundred percent iron and nickel), and others contain significant amounts of water and carbon.

These varied chemical compositions and orbital distributions provide clues about the origin and evolution of the solar system. The asteroids appear to be fragments of larger planetary bodies accreted early in the solar system's formation, and have apparently not suffered as many chemical and thermal changes as the planets and large satellites.

Understanding the origins of the Earth-approaching asteroids is a complex business. Shoemaker and colleague George Wetherill of the Carnegie Institution of Washington suggest that some of the Earth-approaching asteroids are the cores of defunct comets that originated in the outer fringes of the solar system, while others are asteroids from the main belt between the orbits of Mars and Jupiter, perturbed inward toward the Sun by the planets. In both cases, these bodies, if directly sampled, should provide a treasure trove about what was happening early in the formation of the solar system at varying distances from the Sun.

The Earth-approaching asteroids and comets appear to be the parent bodies of meteorites that land on Earth. Analyses of meteorites reveal a great variety of chemical types and histories, with some ages going back to the primordial solar system. But the samples are not completely pristine. Earthly meteorites are weathered by their fiery entries into the atmosphere and subsequent unrelenting water erosion before they are picked up and brought into the laboratory.

By looking at craters on the Moon and inner planets, we can get an idea of the history of impact by Earth-approaching bodies. This is harder to do on the Earth because all but the most recent craters are obliterated by water and weathering. Counting lunar, Martian and Mercurian craters reveals that, during the early epochs of the solar system, there were a lot more Apollo-type objects floating around than there are now. Most of the objects have been swept up by the planets. Asteroids perturbed inward from the main belt replenish the supply of Earth-approachers, but the rate of replenishment appears to be insufficient to account for the entire supply of Apollos. This has created a scientific puzzle: where do most of the Apollo asteroids come from?

On the basis of meteorite analyses and telescopic observations of the light reflected from asteroids, Wetherill suggests that most iron meteorites come from the inner part of the main belt, along with a significant yield of stony meteorites. Most, if not all, meteorites are either Apollo objects or are the remnants of collisions between Apollo asteroids and main belt asteroids.

In any case, we need a source of replenishment for Earth-approaching asteroids because they cannot survive in their current unstable orbits. Scientists who study the changes in their orbits have concluded that all currently observed Earth-approaching asteroids will eventually strike the Earth, Venus or the Moon, and most of the events will occur within the next 100 million years, a mere fiftieth of the age of the solar system. On astronomical time scales, Apollo asteroids are short-lived objects. On a human time scale, the hazard of an earthly cataclysm is remote but nonetheless real.

A Space Resource

Some of the Earth-approaching asteroids are remarkably accessible to spacecraft. John Niehoff has calculated that a spacecraft, launched in 1992 from the shuttle by an upper stage rocket, could loop in a lazy coast around the Sun to rendezvous with the asteroid Anteros, grab a one-kilogram sample, and return it to the Earth's surface three years later.

Small asteroids are irregular in shape because their gravity is not sufficient to crush them into spheres. They may resemble the tiny moons of Mars. A person standing on a three-kilometer-diameter asteroid could easily jump off its surface and never come back. This lack of gravity turns out to be a convenience to the visitor: no retrorockets are needed to "soft-land" a spacecraft.

At times, the energy cost of going to a convenient Earth-approaching asteroid can be less than that required to land on the Moon, and efficient, low-thrust propulsion systems can be used. One idea is to use an electromagnetic motor called a mass driver. Solar-powered superconducting magnets lining a long and narrow tube accelerate pulverized asteroidal material as reaction mass or fuel. In this way, very large asteroidal fragments can be moved cheaply. The energy from the Sun and fuel from the asteroid are free. Thus the Earth-approaching asteroids can be an abundant, accessible, cost-effective and versatile source of materials for space industry.

These visions are not new. As early as 1900, the Russian schoolteacher and scientist Konstantin Tsiolkovsky envisioned the asteroids as human habitats. This idea has since been amplified by Dandridge Cole, Arthur C. Clarke, Gerard K. O'Neill and others.

But recent progress in asteroid science, the existence of the space shuttle, the development of satellite solar power and space manufacturing using nonterrestrial materials as viable engineering concepts, and our perception that humanity is pushing to its limits of growth in energy, food and metals, can suddenly elevate the study of asteroidal resources from imagination to economic reality.

In the summer of 1977, a group of scientists and engineers met at the NASA Ames Research Center to consider scenarios for the retrieval of asteroidal materials for space industry. They concluded that a 2-million-ton, 100-meter-diameter asteroidal chunk could be gently nudged by a solar-powered electromagnetic motor to a safe orbit above the Earth. The trip would take four years, using mined asteroidal debris as fuel. The remains of the asteroid could be processed into satellite power stations, and fuel from the first, small asteroid fragments would allow us to retrieve much larger asteroids. The asteroid study group found that, after a few billion dollars of investment, the Earth-approaching asteroids are a better source of materials for space construction projects than either Earth or the Moon because of the ease of transport and variety of materials available.

There are several other economic schemes for using asteroidal materials. Michael Gaffey and Thomas McCord have suggested that an iron-nickel asteroid could be recovered to replenish the world's supply of these metals. While in space, the asteroidal fragments could be made into a metal foam which would enter the atmosphere, land in the ocean and float.

Apollo asteroids have already created resources for the Earth. In Ontario, Canada, a large circular area called the Sudbury Astrobleme originated from the impact some 2 billion years ago of an Apollo asteroid. This asteroid either provided or unearthed one half of the nickel used in the world during the last two decades.

Mining engineer David Kuck justifies a voyage to an Earth-approaching asteroid on the basis of the platinum and other rare metals that may be present. Taking the fractional quantities available in some common meteorite samples, Kuck surmises that there could be millions of dollars worth of extractable precious metals in a 100-meter asteroidal chunk.

Independent of the metals and minerals value of the Earth-approaching asteroids is their potential for space agriculture. As wild as this idea may first sound, the asteroids contain all the materials required for growing crops and feeding animals in space—metals, glass, water, carbon, nitrogen and phosphorus. Only seeds and Noah's Arks need initially come from Earth.

Potential Danger

But there is another dramatic dimension. The Apollo asteroids themselves might provide ample incentive to explore and exploit them. What hazard do they pose to the population when one crashes into the Earth? According to Theodore Taylor, a one-kilometer-diameter asteroid striking the Earth could cause tidal waves, change the atmosphere and global climate, wipe out major food-growing areas and incinerate thousands of square kilometers of fields and forests. Taylor reasoned that we could foresee these potential cataclysms and engineer the means of preventing them.

An Apollo asteroid may indeed have wreaked havoc on Earth. Luis Alvarez and his co-workers found deposits containing 30 to 160 times normal Iridium levels dated to an event 65 million years ago, precisely at the time of the Cretaceous-Tertiary extinctions. The Alvarez group has an interesting hypothesis to account for the extinctions and Iridium—the impact of a ten kilometer Apollo asteroid. They suggest that pulverized rock ejected by the impact would float in the stratosphere for three to five years and be distributed worldwide. "The resulting darkness," they write, "would suppress photosynthesis, and the expected biological consequences match quite closely the extinctions observed in the paleontological record." Others have argued that water vapor, rather than dust in the atmosphere, was the chief climate modifier, but either way, the evidence for a connection between an impact and the end of the dinosaur age is strong.

Another more recent event is worthy of note. On June 30, 1908, a brilliant fireball exploded five kilometers above the pine forests of Tunguska, Siberia. About 1,500 reindeer were killed and a man standing on his porch was knocked down. Shock waves registered on seismographs and air compression waves were detected in remote Europe. The explosion released ten megatons of TNT-equivalent energy. An impacting body, possibly a small comet or extinct comet-turned-asteroid, was the likely cause. The loose agglomeration of dust and ice, about 60 meters across and weighing 100,000 tons, exploded in the air, causing a horrifying disaster which, fortunately, took place in an uninhabited area. Events on the scale of Tunguska may happen at frequencies on the order of decades to centuries, and could trigger a nuclear war out of misunderstanding.

The Challenge of Asteroids

It appears that the same engineering challenges as those for retrieving asteroidal resources apply to the warning and diversion of a potential collider. History has shown that the Earth-approaching asteroids come to us, creating havoc and excavating resources; now are we ready to go to them to avoid havoc and expand our earthly limits of growth. In practical terms, how can these dreams take place? What are the steps needed to get there from here?

We go back to the modest efforts of Eleanor Helin and her co-workers at Mount Palomar. Most likely, our first target will appear as a streak on one of their plates. The ideal candidate will need to have an orbit similar to the Earth's and a spectral signature showing raw materials that will be useful to us—both scientifically and practically. That will probably mean a "carbonaceous" asteroid, a dark object with up to 20 percent water and a few percent carbon. There is now evidence that some of the Apollo objects are carbonaceous, but we cannot know for sure what the chemistry and mineralogy are until we send an automated probe to rendezvous with an asteroid.

Unfortunately, NASA has no current plan to do this, but the scientific, resource and hazard-avoidance potential of the Earth-approaching asteroids will probably change that thinking and provide some exciting opportunities for the future. Whether some of us now realize it or not, near-Earth space is loaded with energy, materials and exploratory opportunities that beckon to the venturesome and enterprising soul. It will all happen, probably sooner than we think.

Brian O'Leary is an astrophysicist, writer, lecturer and former astronaut. His book on the exploitation of space resources, The Fertile Stars, *is published by Everest House.*

MARS— A HUMAN OUTPOST

by Leonard David

No one planet has piqued our curiosity more than the fourth planet from the Sun—Mars. This red world travels in an orbit which swings it Earthward no less than 34 million miles away. Mars has served both as an inducement for scientific speculation and as grist for the imaginings of countless science fiction authors.

So enamored were we with Mars in the past, we gladly transformed it into Earth's celestial next-door neighbor, abuzz with life. The French Academy of Sciences in 1900 tendered 100,000 francs to anyone who "succeeded in establishing communication with another world, *other than Mars.*" The rules demanded such a caveat, explained the Academy, because contact with intelligent beings on Mars was deemed much too easy!

Mars as a planet, teeming with intelligent life, was bolstered by the turn-of-the-century observations and writings of astronomer Percival Lowell. Lowell was convinced that an intricate network of water-carrying canals fed a slowly dehydrating population on Mars. In his 1908 book, *Mars as the Abode of Life,* Lowell commented:

"There are celestial sights more dazzling, spectacles that inspire more awe, but to the thoughtful observer who is privileged to see them well, there is nothing in the sky so profoundly impressive as these canals of Mars. Fine lines and little gossamer filaments only, cobwebbing the face of the Martian disk, but threads to draw one's mind after them across the millions of miles of intervening void."

In more than twenty launch attempts, fourteen Soviet and American probes have crossed that "intervening void" since 1962; flying by, orbiting around or landing on Mars. The long distance eyes of United States' robot spacecraft—*Mariner* and *Viking* vehicles—have been crucial in framing our perceptions of the red planet.

And with each data bit telemetered from the planet-snooping robots, our understanding of Mars has been enhanced. Gone are the fictional Martian cities and Lowellian waterways, but what has emerged is a world of astounding beauty and geologic diversity: a polar-capped and rugged land of craters, sand dunes and gigantic volcanos, of immense canyons and global dust storms, territory gouged by river-bed-like channels, mysteriously empty of the flowing waters or ice streams which presumably carved them.

Via the mechanical eyes of two *Viking* landers, replete with sensitive mini-laboratories to assess the chances for Martian life, our attention was captured in a strikingly different way. With its pinkish sky, gently rolling hills coated with reddish-gray soil, sand dunes, and strewn rocks of all sizes, Mars was reminiscent of an oddly-colored Earthly setting in Africa or the American Southwest.

"Today we have touched Mars," commented an inspired Ray Bradbury, the science fiction author, during ceremonies held at the Jet Propulsion Laboratory in July, 1976. "There is life on Mars, and it is us—extensions of our eyes in all directions, extensions of our sense of touch, extensions of our mind, extensions of our heart and soul have touched Mars today. That's the message to look for there. We are on Mars. We are the Martians."

Yet the mechanized presence of robot brethren is far from a truly human touch. As far as Mars is concerned, where do the robots end and humans begin? Following the pattern set by the *Apollo* lunar program—a series of automated reconnaissance vehicles followed by manned landings—Mars visits by humans appear overdue. But from NASA, there is as yet no cry of "send in the astronauts." The space agency proposes continuing the automated exploration of Mars for some time to come, and there is no immediate plan even for that class of mission.

A shopping list of candidate automated missions has been drafted by engineers at JPL:

PHOTOS: JPL/NASA

ABOVE: Frost on Utopia Planitia was photographed by Viking *Lander 2 on May 18, 1979, nearly two years after its landing on Mars. A thin layer of water ice coats the rocks and soil. Scientists believe dust particles in the atmosphere pick up bits of solid water, but this frosted dust is not heavy enough to settle to the ground. When it combines with carbon dioxide, the dominant component of the Martian atmosphere, the particles sink to the surface. Warmed by the Sun, the carbon dioxide evaporates, leaving the dust and water behind.*

LEFT: The Mariner *and* Viking *missions to Mars found no trace of the system of canals imagined by Percival Lowell, but the spacecraft did return pictures of channels engraved in the Martian surface. The channels are suggestive of flood waters cutting across the plain, perhaps the result of melting of ground ice. Some scientists believe Martian flow features indicate mudflows or the movement of glaciers.*

■ ***A Mars Orbiter:*** A relatively inexpensive probe would circle Mars from pole to pole, globally mapping the planet's geological, geochemical, atmospheric and magnetic properties. This spacecraft would be a close derivative of the Venus Orbiting Imaging Radar (VOIR).

■ ***Mars Penetrators:*** Equipment-laden missiles would be shot from orbiting carriers and would plunge into Mars, establishing a network of stations widely distributed over Mars' surface.

■ ***A Mars "Air Force":*** Computer-controlled airplanes would be dispatched from a circling spacecraft/aircraft carrier. These planes could circle volcanos and dip into canyons, carrying cameras, deploying instruments to selected sites, and possibly landing to collect soil samples.

■ ***The Mobile Lander:*** An autonomous rover would drive for miles across Martian terrain, equipped with a wide variety of sensing devices and sampling tools. The vehicle could traverse more than one hundred kilometers in its ninety-day lifetime, and could intensively examine a number of sites and deploy scientific packages at selected spots.

■ ***A Return Sample Mission:*** In this, the most costly and complicated approach, a landing vehicle would gather Martian rocks and soil, launching the material back to Earth in a sealed container. The returned samples would undergo laboratory scrutiny far greater than can be accomplished by remote analysis on Mars, including age dating and detection of subtle clues to the planet's history and its ability to support life.

The challenge of adequately surveying a planet as complex as Mars is exemplified by this variety of proposed projects. Barring manned Mars expeditions, at least for the time being, NASA has advocated both mobile rovers and sample return, but this plan has not received unanimous support from the scientific community.

Have we reached a crossroads in Mars exploration, where human investigators are required to maximize scientific return? Dr. Benton Clark, a planetary scientist for Martin Marietta in Colorado argues: "Science progresses ultimately at the hands of the scientist. Sophisticated instruments are merely the tools by which we enhance and extend the fundamental senses we were originally endowed with."

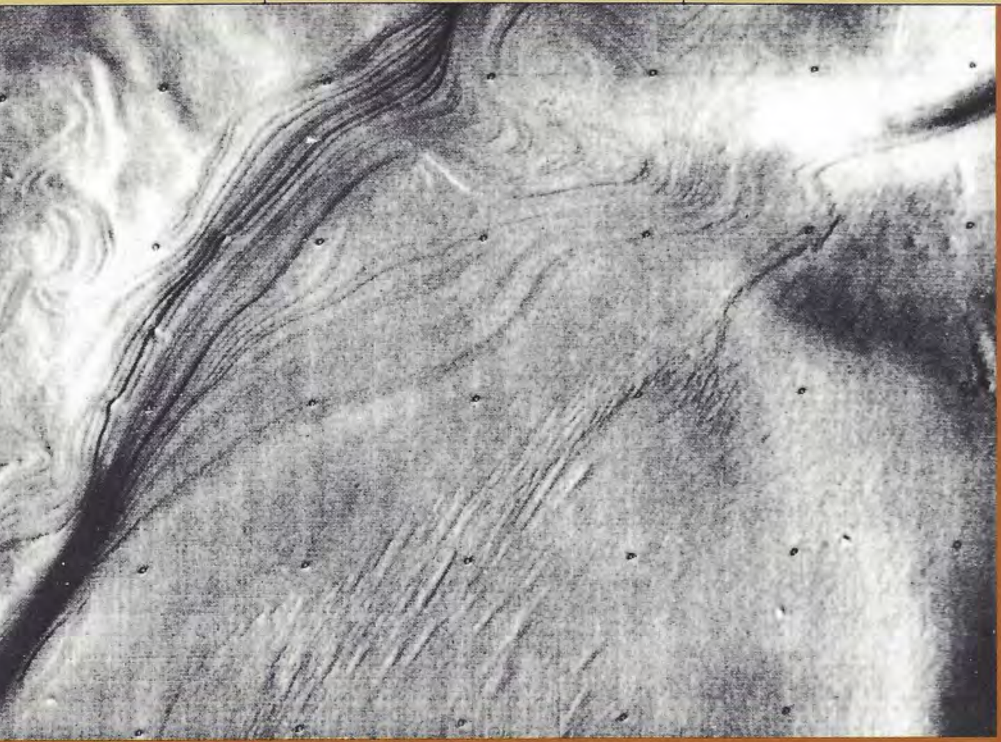
There are a number of duties better assigned to humans than machines, Clark contends. A field geologist on Mars would cover a given site in more thorough detail a hundred to a thousand times faster than a rover remotely-controlled from Earth.

In addition, setting up and retrieving surface equipment for seismic and electrical sounding studies is a straightforward proposition for the human touch. A similar task is anything but simple for automatons, claims Clark. "Deep drilling, to one hundred meters or more, is quite feasible by astronauts using portable equipment, and vastly more important from a scientific standpoint than the one-meter drill core currently planned for automated spacecraft exploration."

Martian planetologists could launch balloons and/or sounding rockets to probe Mars' upper atmosphere, recovering the scientific gear for reuse, suggests Clark. "Undoubtedly, a highly mobile rover would be driven over long distances to reconnoiter as well as conduct planned traverses through major geologic units identified from orbital remote sensing. During these wide-ranging travels, the scientists would carefully document on film the significant features on the terrain. In this capacity, they would provide an immense degree of data compression, in the sense of eliminating redundant or inconsequential picture-taking that a rover with no evaluation capability would be obliged to acquire."

The Martin Marietta planetary scientist, while tipping his hat to the results of *Viking*, offers one additional finding relayed from the dual Mars landing missions. "A major lesson of *Viking* has been that spacecraft automation will only achieve what is in fact readily achievable. That is to say, the issue becomes the practicality of machine versus the practicality of man. Some complex things are simple to automate; some very simple things are extremely difficult to automate," observes Clark.

Early in 1981, a diverse, multi-disciplinary group of individuals representing academia, government and industry met at the University of Colorado at Boulder to attend a symposium aptly titled "The Case for



ABOVE: Terraces develop where layered landforms are eroded by the wind. These surface features are evidence of cyclical climatic changes on Mars. Mariner 9 *first photographed these regions of the polar highlands, and the features were further investigated by the* Viking *orbiters.*

RIGHT: The north polar ice cap of Mars is surrounded by sand dunes and overlies layered deposits of surface material. Elongated patches of water ice (top) are separated from one another by ice-free terraced slopes. Dark sand streams down a gently curving channel and flows into a broad, delta-shaped dune field which appears as a sinuous pattern of ridges.

Mars." Symposium participants suggested options enabling this country to blueprint a manned sojourn on Mars, the ability to do so unfolding from our burgeoning space program in the next twenty years. In addition, it was concluded that human flight to Mars is a proposition costing significantly less than the *Apollo* program. By borrowing skills and abilities that are to be in place by the 1990's (space construction, solar electric propulsion, permanently occupied orbital habitats, solar sailing, etc.) a manned excursion to Mars is within our technological reach. The conference findings, although preliminary in nature, are a first, and necessary, review of the technological expertise required to establish a human link to Mars.

■ **Philosophy of the Program:** Mars can be a unifying goal for future technological development. Although it is alien to human life forms, the planet has the potential for *in situ* production of life-supporting substances. New technology, including the space shuttle, could make a manned mission to Mars cheaper than the *Apollo* program to the Moon.

■ **Precursor Missions:** To select a base site, a polar orbiter mission is necessary. Water must be located and possible sites examined for safety and scientific interest. A sample return mission to test the possibility of local resource utilization should be carried out. And a manned mission to either Phobos or Deimos could serve as a beachhead to Mars.

■ **Mission Profile:** An external fuel tank for the space shuttle, carried into orbit and equipped with chemical life-support systems, can be used as a Mars transit vehicle. The Solar Electric Propulsion System (SEPS) or a solar sail could be used to carry the craft to Mars. An aerocapture vehicle (a shell to protect the spacecraft from friction caused by entry into the atmosphere) could reduce the fuel necessary for orbit injection. While the medical effects of zero gravity can be overcome, psychological considerations must be paramount in planning the mission. The crew should number at least seven; Earth-based studies suggest that there should be unequal numbers of men and women.

■ **Surface Activities:** Base sites must be chosen for their scientific interest and water supply. Martian resources can be processed to provide a breathable atmosphere, water, fuel, industrial compounds, building materials, fertilizers and soil for food production. The high levels of solar ultraviolet and other radiation reaching the Martian surface and the length of the mission dictate the use of underground habitats. Three types of devices will be needed for surface mobility: 1) suits for the 1–3 kilometer range, 2) manned rovers for the 1–30 kilometer range, and 3) teleoperated vehicles for ranges of 1000 kilometers or more.

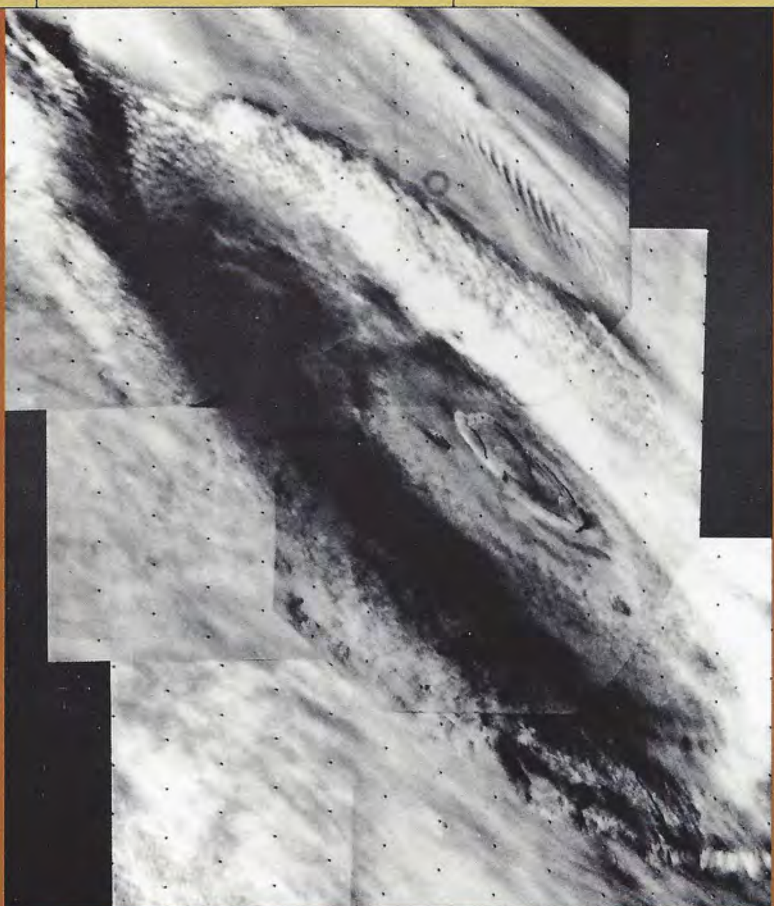
■ **Scientific Questions:** There are two basic questions to be answered by Mars exploration: 1) Is there a native Martian ecology? 2) How does Mars compare with the Earth and other planets?

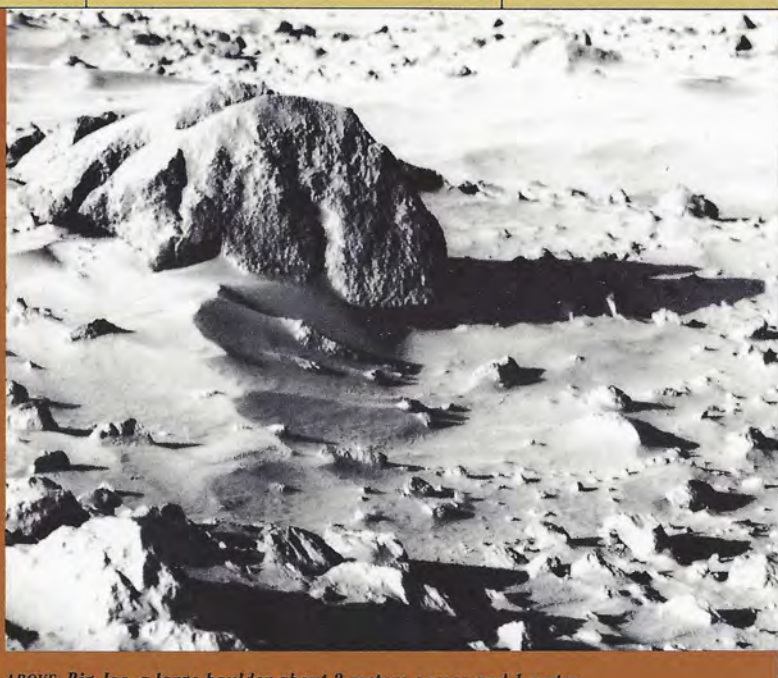
What is missing, however, is a break from the self-imposed moratorium on imagination which has strangled our planetary pursuits. It remains to be seen whether or not a visible U.S. manned space program will stoke the fires of public imagination as did our commitment to human voyages to neighboring Luna.

There is no need for a scientific showdown between robot and human. A melding of flesh and bone with nuts and bolts will tremendously enhance our understanding and use of the red planet. This hybrid approach could lead to data far superior to those gleaned from lonely robot sensors.

It was the spirit of *Apollo* that provided "one small step." But other steps are required. It is logical to consider Mars as that next step. Initial human travels will spawn small Mars bases, later evolving to permanent housing. When our species has occupied this second niche in the solar system, a transformation of the planet will be conceivable. Mars made suitable for the human condition is an ultimate life insurance policy for our species, outward bound to the stars beyond.

Leonard David, a free-lance writer, is editor and programs manager for the National Space Institute in Washington, D.C. An upcoming issue of Science Digest *will carry another of his articles on Mars exploration.*





ABOVE: Big Joe, a large boulder about 2 meters across and 1 meter high, is the companion of* Viking *Lander 1 on the plain of Chryse Planitia. It lies near the rim of an old and degraded crater, and it has been suggested that the boulder was thrown onto the plain by the impact of a meteorite.

LEFT: The great Martian volcano, Olympus Mons, is surrounded by clouds in this photograph taken by* Viking *Orbiter 1. Olympus Mons is 24 kilometers (15 miles) high and about 600 kilometers (375 miles) across at the base. If situated in California, the volcano would extend from Los Angeles to San Francisco. The rim of the multi-ringed caldera (volcanic crater) thrusts up into the Martian stratosphere. The wreathing clouds are thought to be composed of water ice, condensed from the cooling atmosphere as it moves up the slopes of the volcano.

FROM DUST TO CINDERS—A

by Stewart Nozette

Throughout human history, natural philosophers have speculated upon the origin of stars and planets. In the age of scientific inquiry that began a few hundred years ago, these speculations, shaped by the information available in their times, have included various ideas: Was planetary matter pulled out of the Sun by the gravity of a passing star? Did the growing Sun shed a series of rings that formed into planets? Did it somehow collect a retinue of pre-existing bodies from interstellar space? Some of these theories would imply that planets are a very rare phe-

LIFE OF THE SOLAR SYSTEM

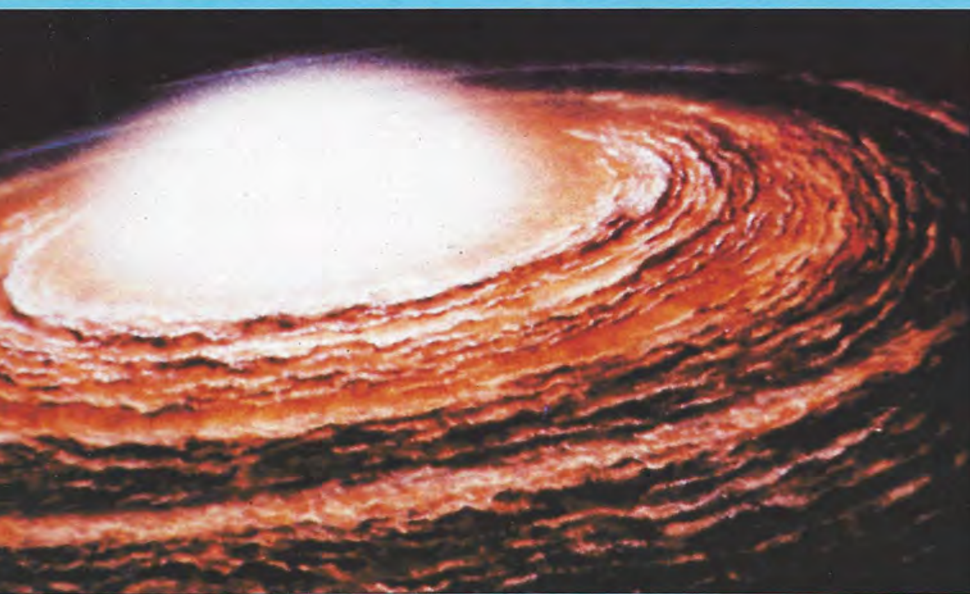
nomenon, while others suggest that planets will be found to be common throughout a typical galaxy.

Modern ideas on the solar system's origin generally take a direction proposed in the 18th century by Laplace. His nebular hypothesis held that the Sun and planets somehow formed from a spinning cloud of gas and dust. Scientists now work with various versions of this hypothesis. The gas pressure in the early solar nebula was probably less than one-thousandth of that of the Earth's atmosphere at sea level; low, but cer-

PRECEDING PAGE:

MOONRISE, 4 BILLION B.C.: During the early evolution of the solar system, the Moon may have orbited the Earth at only one-third its present distance. Tides on Earth would have been huge, regularly sending mountainous waves to crash upon the edges of the young continents.
PAINTING BY DON DIXON.

PLANETESIMAL IMPACT ON THE MOON: In this hypothetical view of an impact on the Moon's far side, the Earth appears at a stage before the continents drifted apart.
PAINTING BY MICHAEL CARROLL.



BIRTH OF THE SUN: Here the artist portrays the forming Sun, shortly before nuclear fusion began and it condensed to a spherical shape. A T-Tauri wind is blowing away unassimilated dust from the edges of the solar nebula.
PAINTING BY DON DIXON.

PLANETESIMALS COLLIDING: In this game of celestial billiards, planetesimals, ranging from a few meters to a hundred kilometers across, collide at random. According to one model of the formation of planets, such collisions gradually brought order to the early solar system and may have formed the terrestrial planets.
PAINTING BY DON DIXON.

tainly not a vacuum. This nebula may have formed as one small part of a very massive interstellar cloud, which could be the parent of hundreds of smaller aggregates. Within this giant cloud, massive stars would be born, live out their short, million-year-lives, and die, shedding their substance into the cloud and enriching it in heavy elements that formed in their thermonuclear furnaces. Supernova explosions would send shock waves into the cloud, increasing the local density enough to start a gravitational collapse and also injecting telltale isotopes. Smaller stars, such as our Sun, forming from small clumps of this shocked and seeded matter, could then live out their much longer and more placid lives, perhaps often surrounded by comets, planets and smaller bodies bearing the chemical imprint of the former cataclysms.

This story is plausible, even compelling, but its details still hold many mysteries. Why do the Sun's planets all revolve in a plane, while asteroids and comets do not? Why do they rotate on their own axes, in a more-or-less upright and regular fashion—except for Uranus and its system of moons, whose rotation axis is skewed almost to the planet's orbital plane? Why are the bodies so regularly spaced at increasing intervals outward from the Sun? Above all, how did the planets, with less than one percent of the mass, acquire more than ninety percent of the angular momentum of the entire system?

What makes us believe that such a chain of events—collapse of a cloud, condensation of bodies—actually took place? In the last sixty years, astronomers, physicists and chemists have worked out a general theory to explain the production of the chemical elements. Stars such as the Sun derive energy by turning hydrogen into helium. In old age, after its hydrogen is exhausted, a Sun-like star will convert helium into carbon, nitrogen and all the elements up to iron. Heavier elements such as uranium may be produced in supernova explosions, the death throes of much larger stars. Recently, chemical and isotopic analysis of the Allende meteorite, which fell in Mexico in 1969, revealed minerals which may have formed in a supernova. Such an explosion would create a variety of short-lived radioactive elements, whose decay can be observed today. In our own laboratories we may have pieces of stellar debris, relatively unchanged in 4.5 billion years.

Using these and other clues, scientists try to construct models of the forming solar system explaining the various properties of the planets. In one model, the elemental composition of material in the center of the disk, near the forming sun, differs from that of material near the edge. For example, ice and water may have been more abundant near forming Jupiter, with iron and rocky material near the Earth and Venus. As we move farther from the Sun, the major bodies become less dense, containing relatively less iron and rock. One model explaining this trend requires only that Mercury formed at a higher temperature and nearer the Sun. But that same model will not predict how the Earth acquired oceans while the Moon did not, nor can it explain the diversity of objects found in the asteroid belt.

In some models, the center of the nebula evolves into a stable Sun in a very brief 100,000 years. Formation of the planets may then take 100 million years. After the Sun turns on, the nebular gas is dispersed by a strong wind of ions streaming from the Sun. Such a process has been observed around objects called T-Tauri stars. Thousands of asteroids and Moon-sized bodies, called planetesimals, may surround the Sun at this point. The planetesimals grow as their gravity sweeps up smaller debris from their surroundings.

In a different model, the nebula itself breaks up into several large gaseous protoplanets which ultimately become objects such as Jupiter and Saturn. In some cases where the protoplanets have enough mass to reach nuclear-reaction temperatures, multiple star systems are formed. Our solar system may incorporate several of the processes described by these different models. In model building we are trying to look backwards in time—a very difficult problem, since the processes that shape planetary bodies can also wipe out important evidence of their birth.

How do we know that the solar system is 4.5 billion years old? Astrophysical comparisons of other stars with the Sun suggest that it is middle-aged for a star of its composition and mass—roughly 5 billion years old. Can we obtain an independent estimate? Yes. Rocks can be dated by examining their radioactive elements, which decay at known rates. In 4.5 billion years, one hundred average atoms of uranium 238 will turn into fifty atoms of uranium and fifty atoms of lead. In another 4.5 billion years, half of the remaining uranium will decay, leaving twenty-five atoms of uranium and seventy-five atoms of lead. Other elements with longer and shorter half-lives can also be used, and when proper care is taken to be sure that today's count relates truly to what was there when the rock formed, the age of the rock can be found.

The oldest isolated rocks on Earth are about 3.8 billion years old. However, meteorites almost all date from 4.5 to 4.6 billion years, even when dated by several methods. On Earth, erosion resets the radioactive clocks by moving the atoms, but meteorites seem to have been undisturbed since their formation. Since many old meteorites are unmelted, scientists believe they are left-over pieces of the material that formed the Earth and planets. On the Moon, which has little erosion, the *Apollo* astronauts found rocks dating back to the same magic 4.5 billion years, dated by methods independent of those used to date Earth rocks and meteorites. The youngest rocks on the Moon are over 3 billion years old—still quite ancient by Earth standards.

So it seems that the Earth, Sun, Moon and meteorites are all about the same age, within the errors in independent measurements. This is very good scientific evidence that these objects formed at about the same time: 4.5 to 4.6 billion years ago.

There are still many things we do not know about the history of the solar system. We have only sampled a few bodies directly, and we have no measured dates from Mercury, Venus, Mars or any asteroids that are not represented by meteorites. We can tell relative ages on Mars by noting that older regions have more impact craters than younger regions. But absolute age dating of Martian samples awaits their return to Earth for isotopic laboratory analysis.

Our simple general models of planetary formation still do not tell us exactly how the Moon formed, why Venus and Earth are so different, or why Uranus is lying on its side. But we are beginning to understand, by actual exploration, some of the events which led to the birth of our planet.

While the story so far has concerned the past, let us take a brief glimpse at the future. So long as the Sun continues to supply its present amount of energy, the terrestrial planets will remain about the same as today. Earth and Mars may undergo periods of climatic change, although today we cannot predict the frequency or duration of these changes. On Earth, the process of plate tectonics will continue to rearrange the patterns of continents—already we see a new ocean basin opening at the Red Sea. Impacts will also continue to change the faces of the planets and satellites. These changes are the same gradual processes which have shaped the solar system up to now.

More fundamental changes will probably not occur for 4 billion years. At that distant time the Sun will have used up most of its hydrogen fuel. The Sun holds its present size through a delicate balance between the pull of gravity and the outward push of its central nuclear furnaces. When the hydrogen is used up, the Sun will contract and the pressure and temperature of its interior will rise. These higher temperatures will allow the Sun to convert helium into carbon, providing a new energy source to halt the contraction. When the Sun begins to burn helium, it will begin to expand, due to the power of the new energy source. It will turn into a giant red star, engulfing the inner planets. The oceans will boil away and all life on our planet will end. The Earth will be burnt to a cinder.

After the Sun has exhausted all possible nuclear fuels it will contract into a white dwarf star, a body about the size of Earth and composed of material so dense that one teaspoon of it would weigh tons. Then over many more billions of years, the white dwarf star will cool and the solar system will grow cold and dark. The only remaining heat will come from the leftover heat of formation still carried by the surviving planets.

These predictions are made by scientists who study the origin and evolution of stars. They are done mathematically, using our current knowledge of the physics and chemistry of stars. The details of our story, like the timetable of evolutionary events, may be modified as we acquire new knowledge, but the basic predictions should remain unchanged. We can be sure that nature will eventually bring down the curtain on our solar system.

For the first time in human history, we have a creation story which can be tested by further exploration. It may turn out that some of our ideas are wrong, but we will enjoy the process of finding out. Our present knowledge also suggests that the planetary systems should be fairly common throughout our galaxy. Whether or not these systems harbor intelligent life which shares our curiosity about the lives and deaths of stars is a question to be answered only by looking.

Stewart Nozette is a graduate student in the Department of Earth and Planetary Science at the Massachusetts Institute of Technology in Cambridge.

Missions to the Far Outer Planets

by Susan J. Kovach

A new age in planetary exploration began on December 3, 1973, when *Pioneer 10* flew by the planet Jupiter. For the first time an emissary from Earth ventured to the outer planets of our solar system. It had successfully navigated the asteroid belt, survived the enormous magnetic and gravitational forces of giant Jupiter, and stood the test of time through the inhospitable environment of space to travel farther from Earth than any other spacecraft. *Pioneer 10* proved that we could leave our nest of inner planets and boldly explore the far reaches of our solar system. *Voyager* followed, taking us to close encounters with Jupiter and Saturn. And now we are preparing to rediscover the mysterious far outer planets—Uranus, Neptune and Pluto.

Missions to the far outer planets are the most ambitious ever conceived. The vast distances and the years of flight time require new technology, particularly in the areas of spacecraft lifetimes and autonomy, telemetry and data transmission, propulsion systems and science instrument integration. We can have these new techniques before the end of this century. But why should we explore the outer planets? What do we hope to learn? And just how are we going to get there?

To answer these questions, we need only go back in history. In a matter of several centuries, a very short time in the lifetime of our planet, we have gone from continental exploration to global exploration, and to the exploration of the Moon and inner planets. We are curious, we imagine other worlds and distant stars, and dream of traveling to them. Just as our ancestors looked out over the oceans and determinedly crossed them to unknown worlds, we now take those same steps to fulfill our intellectual curiosity about the unknown worlds of today. We need to know what lies at the boundaries of our solar system, for what we learn may lead us to a better understanding of who we are and why we are, and our place in the solar system and the galaxy. The Earth contains only about 0.2 percent of the planetary mass of the solar system; over 99.6 percent of the mass orbiting the Sun lies in the outer planets.

What we hope to learn can be summarized in five principal areas: 1) the planets—their internal structures, surfaces and atmospheres; 2) the planets' satellites—their internal structures, surfaces and possible atmospheres; 3) any ring structures the planets may have; 4) the planets' magnetic fields, their magnetospheres, and the magnetospheric interactions between trapped radiation, the planets and their satellites; and 5) the interplanetary environment beyond the orbit of Saturn.

The far outer planets—Uranus, Neptune and Pluto—are quite different from the giant planets Jupiter and Saturn. All are smaller and colder. Uranus and Neptune are composed of a smaller proportion of hydrogen and helium and a larger proportion of heavy elements than Jupiter and Saturn. Pluto is apparently a snowball of frozen gases; its surface is believed to be largely covered with frozen methane at a temperature of about −230° C.

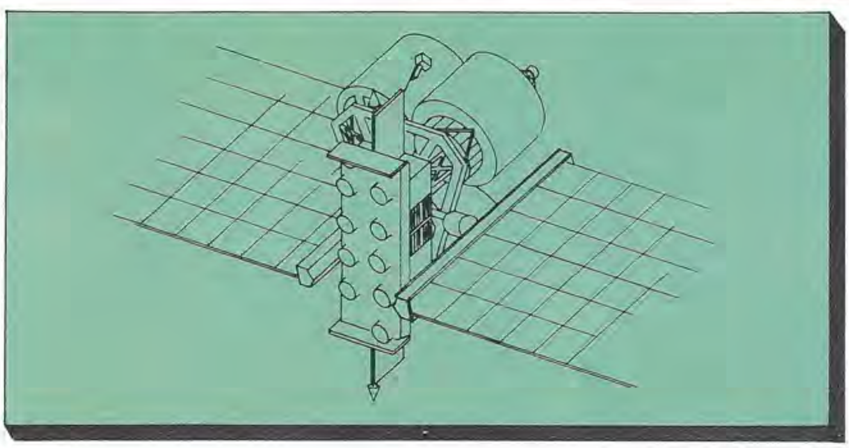
Uranus' axis of rotation is nearly in the plane of its orbit, which gives the planet extreme seasons at its poles. Each pole experiences a 42-year "summer" and a 42-year "winter." Uranus has a ring system and five known satellites, and this system of rings and moons presents itself edge-on to the Earth every 42 years. Beneath its atmosphere, Uranus is believed to have a rocky core about 10,000 miles in diameter, covered with a layer of ice 5,000 miles thick. The rocky core and ice layer together account for about four-fifths of the planet's mass, but the overall density of Uranus is low, due to its extensive gaseous atmosphere.

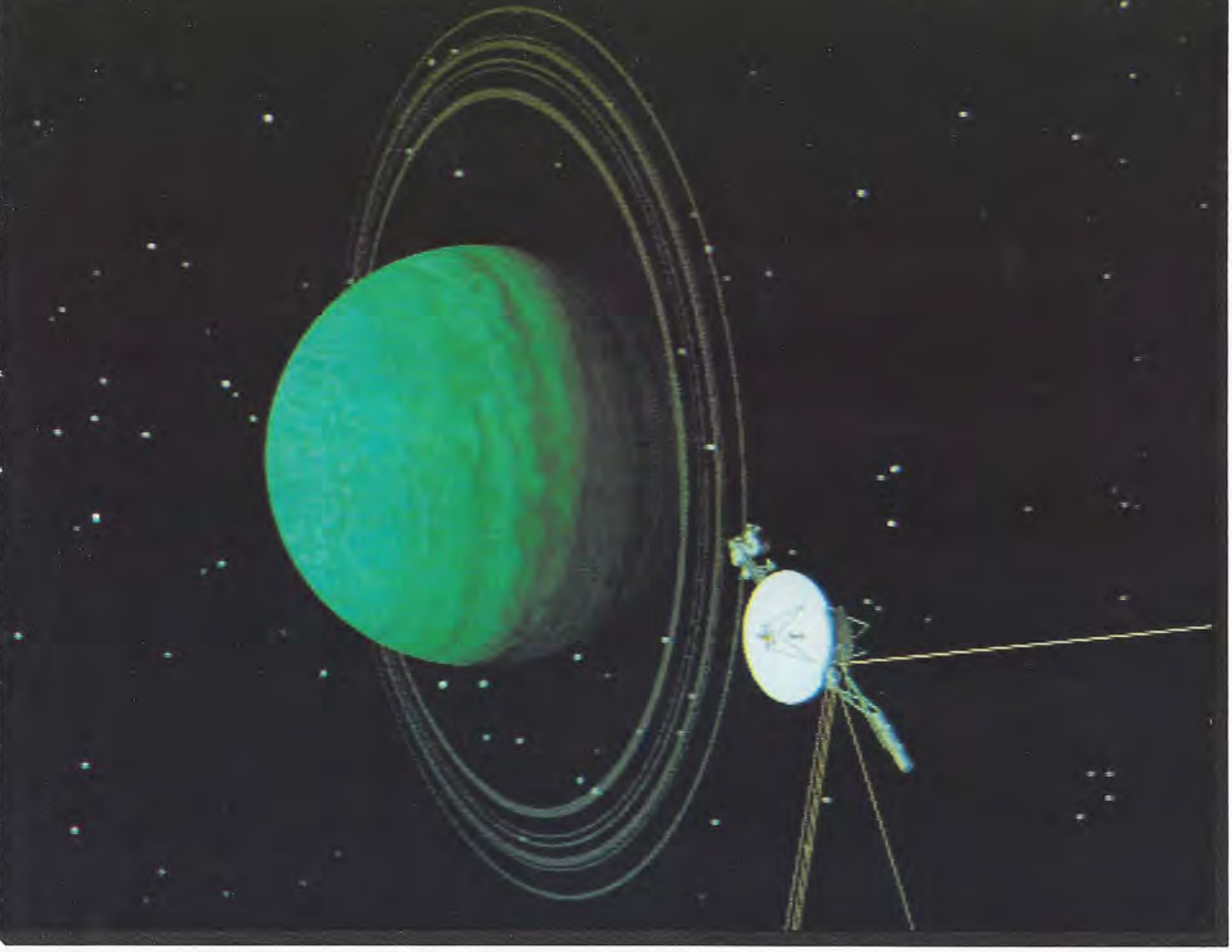
In size and structure, Uranus and Neptune are the most similar of all the planets in our solar system. The interior structure of Neptune is believed to be virtually identical to that of Uranus; over three-fourths of its mass is contained in the ice-coated core. Neptune has two known moons, Triton and Nereid. It has been suggested that Pluto was once a moon of Neptune, and that a close encounter of Pluto with Triton ejected Pluto into a separate orbit around the Sun and threw Triton into a retrograde (the direction opposite the motion of most planets and satellites) orbit about Neptune. The orbital eccentricity of Nereid is further evidence of some highly unusual event in Neptune's past. This eccentricity is the largest for any known satellite; the distance of Nereid from Neptune varies by over 5¼ million miles.

Pluto has a highly unusual elliptical orbit—between January, 1979 and March, 1999 it is closer to the sun than Neptune. The planet takes 247.7 years to complete one orbit and will not return to the position in which it was discovered until 2177. Pluto seems to be no more than 2,000 miles in diameter and is the smallest known planet. It has one moon, Charon, discovered in 1978. Charon's existence enabled astronomers to calculate Pluto's mass at about 0.002 the mass of Earth. Pluto's nature suggests many possibilities, one being that it is the brightest member of a swarm of small planets moving in inclined, elliptical orbits in the outer regions of the solar system.

Each of these planetary systems is unique.

SEPS SPACECRAFT
(Solar Electric Propulsion System)





VOYAGER 2 AT URANUS: This computer graphic simulation shows the *Voyager 2* spacecraft shortly before its Uranus encounter on January 24, 1986.

REPRODUCED COURTESY OF CHARLES KOHLHASE AND JAMES BLINN OF NASA/JPL.

Evolution in the far outer solar system may not be well represented by evidence gathered at Jupiter or Saturn. We have studied the rings of Jupiter and Saturn, and Uranus also has a ring system. Could Neptune have rings, too? Do these ring systems interact with the planets' magnetic and electric fields? This is strongly suspected at Saturn; is it also true at Jupiter and Uranus?

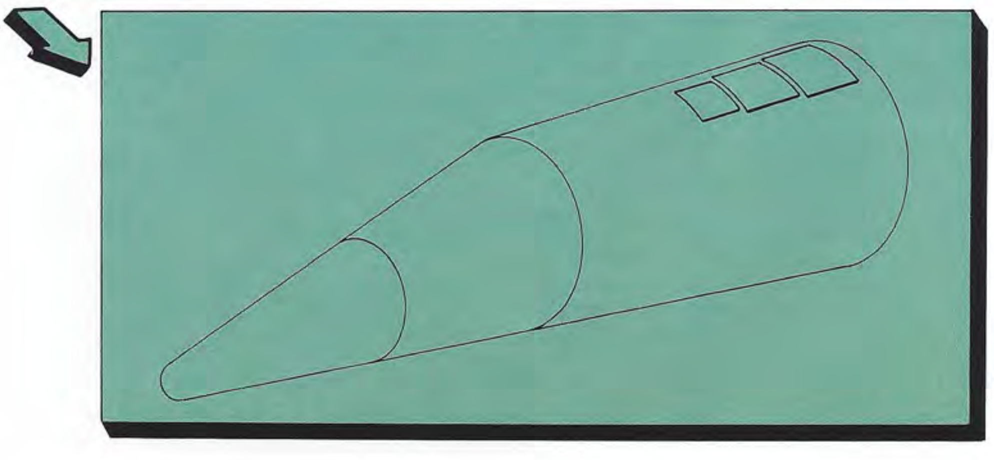
The outer planets provide a wide variety of satellite types and sizes to study. Most fascinating is the study of the interplanetary environment beyond Saturn out to the heliopause, that boundary where our Sun's influence is replaced by that of the interstellar medium and the stars.

To study these many things, new scientific instruments are being developed—instruments such as synthetic aperture radars, which could see through cloud covers to map planetary surfaces. These instruments create new problems in spacecraft design. Larger power sources are required. To survive the years of flight time, these instruments need redundancy in their electronics, which makes them larger and heavier. Since payload mass and size are critical, new propulsion systems are necessary, or we must combine several functions into one instrument. With these problems, a spacecraft such as *Voyager* could not accomplish these missions. New spacecraft and new delivery modes are needed if we are to get there at all.

How we get there is now being studied by NASA. Its Outer Planet Exploration Program consists of studies in three areas: 1) orbiters with probes to three major bodies and a flyby of Pluto; 2) the planetary probes option, with flyby probe carriers; and 3) the Saturn-only program, similar to the *Galileo* Jupiter orbiter. Reaching the far outer planets can require ten or more years of flight time. One method of shortening the time is to use "gravity-assist," such as *Voyager* used. Spacecraft can get an additional boost from the gravity of a large planet, like Jupiter or Saturn. Without this boost, *Voyager* could not have made it to Saturn as quickly as it did. There are several other ways to provide additional delivery capability. The Solar Electric Propulsion System, or SEPS, is one method under study. A SEPS stage uses solar panels to produce electricity which powers mercury ion engines. These engines provide a continual low thrust which can reduce flight time by several years. Solar power, however, becomes less useful the farther a spacecraft travels from the Sun.

Another delivery mode that reduces flight

AEROCAPTURE SHELL



PLUTO AT PERIHELION: In this highly speculative painting, the Sun is seen from the surface of Pluto at perihelion, the point in its orbit when it is closest to the Sun. A tenuous methane atmosphere has been detected around Pluto. Frozen crystals of methane might create "sun dogs" around the Sun as it is seen through the atmosphere.

PAINTING BY DON DIXON.

time is aerocapture. Aerocapture permits placing a spacecraft in planetary orbit without the aid of massive chemical retro-propulsion systems. The resulting reduction in spacecraft mass markedly reduces flight times to the outer planets. The aerocapture device is a shell that encloses the entire spacecraft, except for the necessary navigation and communication instruments. On arrival at the planet, the spacecraft would enter the upper atmosphere; the aerocapture shell would slow to orbital speed and then be jettisoned, leaving the spacecraft in orbit. One mission currently being studied for aerocapture is a Titan orbiter with a probe to Saturn. Aerocapture technology has been only moderately funded and its realization is still in the future, but it does offer new prospects for orbital exploration of any planets that have atmospheres.

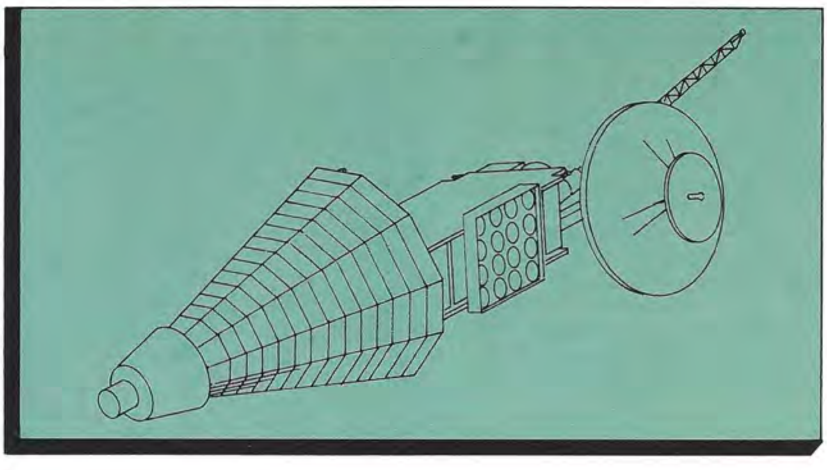
Another promising system is NEPS, the Nuclear Electric Propulsion System. NEPS uses mercury ion engines like SEPS, but the power plant is a nuclear reactor, which can provide 100 to 400 kilowatts of electric power. This is enough power not only for the ion engines, but for many new, high-powered scientific instruments. A NEPS-powered spacecraft could reach Neptune in only nine years. It could also put a payload in orbit around Pluto, something no other system currently under study could do. It can "gracefully" approach a planet—stop way out and move in very slowly—and achieve any orbit desired. But NEPS could not be ready soon; current studies assume a first NEPS flight in 1999.

Considering all of these options, the flight times range from 3 to 14 years. New technologies could enhance these missions considerably. But the Outer Planets Exploration Program faces several challenges: spacecraft must have 10–21 year lifetimes, costs must be kept down, new scientific instrument design is essential, new delivery methods must be found, and better and faster ways of returning information must be developed.

Is it worth it? Outer planet exploration is exploration in the widest sense. To a great degree, we don't know what we'll find at those far-distant worlds. In past planetary exploration we have always been surprised, and as we move outward this will continue. But all the while we will be learning more about the central question: How did our system, our own world, and we ourselves come to be? Going to the far outer planets will give us new models that may help us learn what our place is in the universe.

Susan J. Kovach is a spacecraft configuration engineer at JPL. She recently completed a study on the far outer planets mission and is currently working on NEPS, the Nuclear Electric Propulsion System.

NEPS SPACECRAFT
(Nuclear Electric Propulsion System)



News & Reviews

by Clark R. Chapman

August 1981: *Voyager 2* encounters Saturn, then passes on to the blackness of the outer solar system. It marks the end of the beginning of humanity's venture away from our maternal world. *Life* magazine summed up the past fifteen years of planetary picture-taking with a cover story in its June, 1981 issue. Now, during a lull in planetary exploration, we look toward the future; August, 1981 can mark a new beginning, depending on the foresight of the powers-that-be in Washington toward renewed exploration, understanding and conquest of the solar system.

In a new book, *2081: A Hopeful View of the Human Future* (Simon and Schuster), Gerard O'Neill tries to predict what life will be like a century from now. O'Neill's is a technological projection of a world with underground vacuum transportation, climate-controlled towns and robotic household delights. In this book, concepts such as "small is beautiful" and "limits to growth" are anathema, for O'Neill believes that our salvation lies in an inevitable—and imminent—breakout into space. Puzzled by NASA's (and America's) general lack of faith in his vision, O'Neill nevertheless expresses confidence that space colonies will be replicating rapidly a quarter-century from now and a majority (!) of Americans may live in space by 2081. Perhaps.

O'Neill is conscious of the pitfalls of prophecy, but nonetheless he goes at it with enthusiasm. He recounts the failures of the visionaries of 50 and 100 years ago to predict the rapid pace of technological advance; thus, he justifies his own confidence that our great-grandchildren will live to see something like his computerized, mobile world of the future. But science and technology are changed and much more complex in the latter half of the twentieth century. To me, O'Neill's *2081* has the same tone as a mid-1950s issue of *Changing Times* magazine, in which the editors summarized expert opinion about what life would be like in the early 1980s. With few exceptions, *Changing Times* was too optimistic about rapid modernization. They were a little slow on the space program; they didn't predict President Kennedy's national commitment, although they did suggest that a man might reach the Moon in the 1980s. But from cancer cures, to ubiquitous nuclear power, to self-cleaning homes for millions of Americans, the prognostications of the 1950s overlooked the possibility that technological development would become entwined with unpredictable social, political and economic developments. And, of course, they had no inkling of the micro-electronics and computing revolution that has swept across the world. As for the conquest of Gerry O'Neill's "high frontier": while some people try to make it happen, the rest will have to wait and see.

Hurdles to Face

As we face the future, it is fine to speculate about far-flung possible worlds decades and centuries hence. But we must get over a substantial near-term hurdle if we are to pursue our long-term goals. Despite ever-increasing popular interest in the space program and planetary exploration, past and present United States Administrations have taken a stance toward space that is myopic and lethargic at best. In spite of the space shuttle's success, further NASA budget cuts are planned, and the question has risen about whether the space program, and planetary exploration in particular, even has a near-term future in the United States.

The March/April, 1981 issue of *SIPIscope* (a newsletter published by the Scientists' Institute for Public Information, 355 Lexington Avenue, New York, New York 10017) is devoted to the "controversy over the U.S. space program." Jerry Grey and David Kaufman present the perspective of the American Institute of Aeronautics and Astronautics toward the future of the civilian space program, and conclude that the proposed budget cuts constitute "a significant error in judgment."

In an introductory chapter of a beautiful new book, *The New Solar System* (Sky Publishing and Cambridge University Press), Noel Hinners, director of the National Air and Space Museum, addresses the question of why the "golden age of planetary exploration" seems to be coming to an end. His analysis of NASA's planetary program has caused some soul-searching and debate within the space agency's highest levels during the past few months. I am privileged to be one of twenty chapter authors of this handsomely illustrated popular-level book, which highlights the results of two decades of planetary exploration. Planetary Society president Carl Sagan has written the book's introduction.

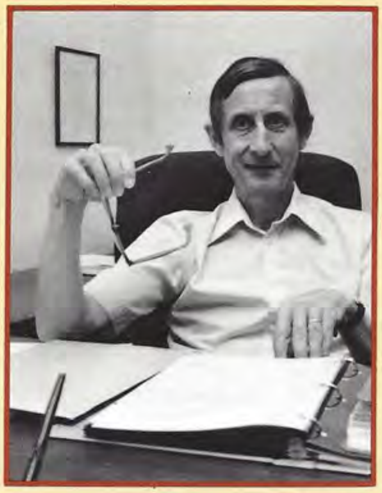
Fruits of the Effort

The rich intellectual fruits of planetary research continue to be reported at scientific conferences. The June, 1981 issue of *Geotimes* (published monthly by the American Geological Institute, 5205 Leesburg Pike, Falls Church, VA 22041) has eleven articles summarizing recent results presented at the Twelfth Lunar and Planetary Science Conference, held in Houston in March. According to Harold Masursky, *Pioneer*'s hints of geological structure on the surface of our neighboring planet Venus do not yet indicate Earth-like plate tectonics, but similar examination of Earth might not show plate tectonics either (a good reason for flying VOIR, the proposed orbiting radar spacecraft). Some new ideas discussed in Houston suggest that some rare meteorites might actually be samples from the planet Mars. The effects of occasional huge impacts of asteroids and comets onto the Earth's surface also generated considerable interest in Houston. And continuing analyses of lunar samples and meteorites are sharpening our views about the earliest beginnings of our solar system.

Another perspective on our origins is gained from theoretical geophysical research and celestial dynamics. The June, 1981 cover story of *Scientific American* describes progress being made on the complicated problem of how the Earth and the other terrestrial planets were formed. George Wetherill outlines the elements of "the planetesimal hypothesis" for planetary formation, in which the planets slowly aggregate by impacts of small planetoids (the "planetesimals"). The rate at which planets grew in the early solar system was controlled by the gravitational effects of the growing planets on the planetesimal swarms and on details of the impact process itself. As we learn more about "why is there an Earth?" we will also learn about what the Earth was like immediately after it was formed. Dependent on how Earth formed are such critical matters as the chemical composition of the surface layers of our planet and whether it formed hot or cold.

Clark Chapman, of the Planetary Science Institute in Tucson, Arizona, is a member of the Galileo *Imaging Team.*

A Talk With Freeman Dyson



Freeman Dyson is a physicist at the Institute for Advanced Study at Princeton, author of Disturbing the Universe and has long been a student of human futures in space. Here are some of his thoughts, as expressed recently during a conversation with our Technical Editor, Jim Burke.

JB: It will be interesting to know what you think about Halley's Comet as an object, the Halley missions in general, and longer-range or deeper implications of understanding cometary matter.

FD: I hope this mission will go through. This is a very good chance to find out how little we know about comets. The main purpose of these missions is to find out what the questions are, rather than what the answers are. We don't know whether anything exists that you can actually call the nucleus of a comet. We don't know what size or shape it might be, we don't know very much about the chemistry of it, so just to see a glimpse of what's there in order to begin asking the right questions — this is what the mission is all about. I don't think it makes much difference whether it's Halley's Comet or any other—the advantage of Halley's Comet, of course, is that everybody's heard of it. This is not the last chance we shall have to look at the comets. Halley's Comet comes only once every 76 years, but there will be others.

JB: Do you believe that we are going to have a big future in space, and what do you see as its potential?

FD: Well, I certainly believe that. And the comets are enormously important if it turns out to be true, which seems very probable, that they are the most abundant bodies in the universe. We have reason to believe there are several billions of comets loosely circulating around the Sun in the outer fringes of the solar system, and it seems quite likely that they may go on essentially all through the galaxy. If the Sun has such a cloud around it, probably most of the other stars do, too. So, these bodies may be the overwhelmingly preponderant living space in the galaxy. If you measure living space by area rather than by volume (and it is area that counts, if you're thinking of places where you can put down your feet) and you wander around the galaxy, it's not necessary to go light years at a time from one star to another. There probably are little oases — very likely they are the things we call comets — spread around through the galaxy only about a light day away from each other. That's at least a possibility.

JB: Are we too impatient in our belief that we should keep pushing on the frontier in all directions?

FD: No, I don't think we are too impatient. The future is infinite. Some things won't happen for thousands of years and there are other things that'll happen very soon. You can't have everything but certainly the way to get there is to start pushing and keep pushing.

JB: In the past, you committed your own personal energies to something which expresses that principle perfectly: *Orion*, a huge nuclear-bomb-propelled spaceship with the potential of carrying hundreds of people throughout the solar system in short travel times. What do you think of it now? Was it a waste of time? Is it still a potential thing?

FD: Well, certainly it wasn't a waste of time because we explored a whole new technology and the base of knowledge of what can be done and what can't be done was very much extended. That was a solid achievement. I wouldn't want to do the *Orion* project now for environmental reasons. It is a very dirty way of getting around the solar system—you use fission bombs on a rather large scale so wherever you go you're spewing forth large amounts of radioactive debris. That doesn't agree with our way of doing things now. Twenty-five years ago, it didn't look so bad, but now we have other ways of going around the solar system which are as feasible as *Orion* and, from an environmental point of view, much cleaner.

Laser propulsion, one of my favorites, has never been tried but I think there's no question it is feasible and would require a development effort of about the same magnitude as *Orion*. This, by the way, is Arthur Kantrowitz's idea, not mine. You'd build a very large laser on top of a mountain and it would send a large beam up into space. This would be a public highway along which small vehicles could coast into space without carrying their own fuel. They would have to carry a certain amount of reaction mass, but they could get into orbit or even escape from the Earth in one stage, so very small vehicles weighing a few tons could leave Earth rapidly and cheaply. The catch is, of course, that you have to build the launch facility before you can start.

JB: You have to punch up through the Earth's atmosphere, don't you?

FD: Well, the Earth's atmosphere isn't all that much of a problem. The greatest advantage of laser as a propulsion system is precisely that it enables you to get off the Earth. It's about the only system I know which is capable of high accelerations and also high efficiency, so it's ideal for the big jump off the Earth into space. Then, of course, once you get into orbit, the nuclear electric, solar sail, mass drivers and other things will be very good for going farther.

JB: Yes, the systems which acquire solar energy and have reaction mass that doesn't come from the Earth are then in their element. Do you visualize that the early steps in this process can be achieved in any other way than through government initiatives?

FD: Yes, I do. I'm not saying that it shouldn't be done by governments, but I think it doesn't have to be done by governments. The problem is to get the customers for the first launch, and once that's been solved it could go pretty well. There's every reason to think that one could launch modest payloads much more cheaply than governments can, just because of overheads of various sorts and the fact that the government has its ingrained routines which are not always cost-effective.

JB: Is there any sign that such a thing could materialize in contemporary society, U.S. or other?

FD: Well, I would say it depends on the time scale. I don't expect this to happen in the next ten years, but I could be wrong. So many things in this world are just quite unexpected. We know how to launch payloads—the problem is, where is the market? Who is going to pay for this and what do they want to do? That's what is so hard to predict.

JB: Would you feel like paying for a ride, and would you go?

FD: Well, I think of my mother who grew up in the good days of Queen Victoria and knew nothing except trains and horses for getting around until she was about 20 years old. At the age of 78 she flew the Atlantic, which to her as a young woman would have been totally unthinkable, so this may happen to me. I wouldn't be too surprised if, at the age of 78, I find myself a passenger going somewhere in the solar system, but I think it's not likely to happen before that. So that gives me 22 years.

JB: Do you see any things which are broadly regarded as, if not crazy, at least useless in the present environment, that to your way of looking have a great potential?

FD: I believe that the most important technological developments of the next twenty or thirty years are going to be biological. That is extremely important in determining what one can do in moving off from the Earth because, in my view, the main purpose of going into space, taking a long view of things, is to expand the sphere of life in the universe—not just human activities, but the sphere of life as a whole.

JB: What do you mean by life?

FD: I mean plants and animals and things we're familiar with. At the moment, as far as we know, they're all crowded on this little planet. Everywhere else we look everything is dead, but there's no reason why life shouldn't adapt itself to all planets, or to all possible environments in the universe. With the kind of biological technology that's now becoming available, we can make this happen. We can tailor gardens to grow on Mars. I think this is very important, not just making it more economically feasible, but making it psychologically more attractive; to go around living in new places if we can grow gardens and make the deserts bloom on a rather short time scale. I think it is much more satisfactory to adapt the plants to the environment than to try to adapt the environment to the plants.

JB: Well, the Martian deserts do have water—it may be very salty, and they do have marginally acceptable temperatures, but I don't know of any kind of bioengineering to enable photosynthesis or some analogous process to take place outside a temperature regime that permits liquid water inside the cells.

FD: You just need warm-blooded plants, that's all. They've got to be able to keep warm, living through the Martian night by having some adaptive phenomenon which maintains their metabolism; feathers or fur or something like that. There are, of course, many such plants. Trees, for example, have bark which is a very good insulator. There's no problem finding furry plants that could deal with one of these problems at a time. What we don't have are plants that could deal with all these problems of living on Mars at once. But with a little knowledge, which we're going to get in the next twenty years, we'll probably know how to do it.

JB: You're playing your ball into my favorite part of the court. Without something resembling off-Earth agriculture, all our expeditions will be out and back with no hope of seeing anything like what happened in the ocean sailing age.

FD: That's true. You've got to be able to grow your own potatoes where you settle. That's absolutely clear. The crucial question is how long it's going to take: twenty years, a hundred, five hundred.

JB: I have frequently advocated early agricultural experiments, even with our present crude biological methods, to be done on the Moon. If a developmental demonstration were to occur and begin to succeed over a long period of time, and a productive ecology, even a small one, were to become present on the Moon and stay there, I would expect some influence on people's thinking. Do you have any thoughts on how that might go?

FD: I absolutely agree. The difficulty with the Moon is that so far we have not found any water there, at least not in quantities enough to be useful. That's one of the things that we desperately want—a polar orbiter mission to search the polar regions of the Moon carefully and see if there are, in fact, large quantities of ice hidden away in the depths of those craters which sunlight never reaches. If we find there are such accumulations of ice, which I think is very probable, that's where you'd go. And once you have water on the Moon in some accessible form, there's no reason at all why agriculture shouldn't be productive. And I agree with you entirely that if you had the choice at the present time, the Moon is where you'd do it, because it's easy to get at and all the problems of supply and communication are so much simpler than for Mars.

JB: Without water on the Moon, there still remains the possibility of finding carbonaceous asteroids in near-enough-to-Earth orbits that they could be a substitute. One hasn't yet been unequivocally demonstrated to be there. But there is certainly every reason from meteorites to say they are there; they hit the Earth every now and then. Would you place equal emphasis on the search for an Earth-crossing asteroid which could be a bonanza of carbonaceous and watery materials?

FD: Well, let's not try to guess what's going to work. As a rule, it's a great mistake to make choices too soon. So I would say I'd much rather go ahead with searching the Moon *and* with searching the asteroids.

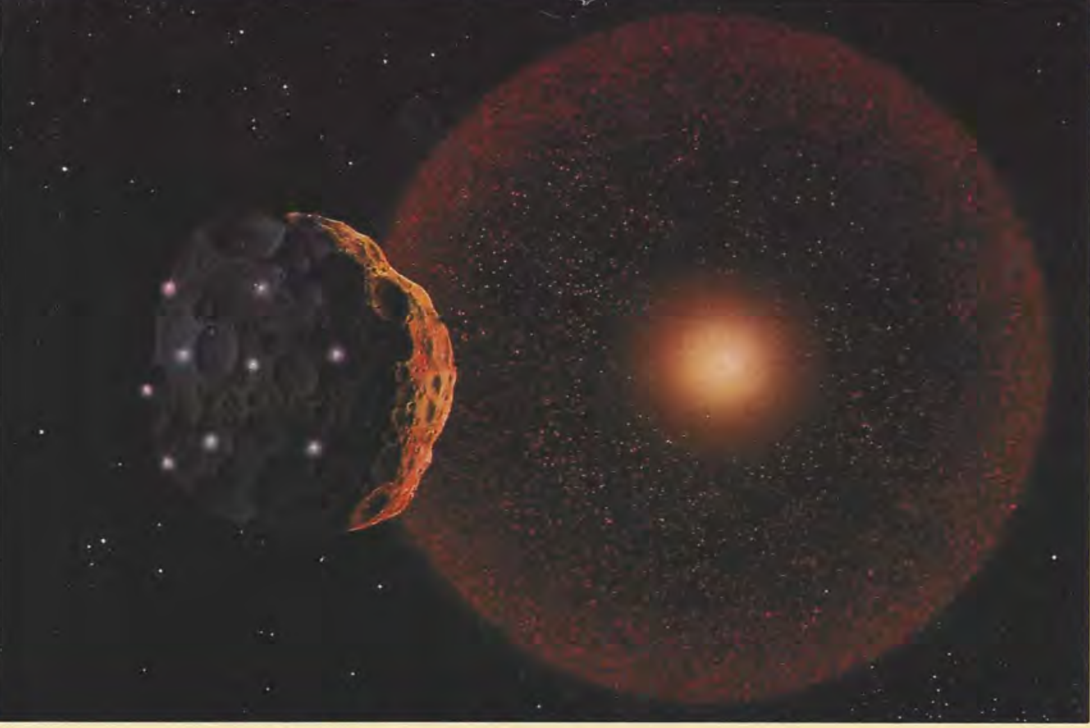
JB: Both of these programs could be carried on at a fraction of the cost of some past planetary explorations. That's not to say that they're easy to sell now.

INTERSTELLAR COMMUNICATION: A radio telescope transmits information about the structure of Terran DNA to the galaxy.
PAINTING BY JON LOMBERG.

FD: That's true. It is essential to the future of space activities that we get accustomed to small missions again. We should be doing regular small missions on a routine basis.

JB: Now let's talk about SETI, the search for extraterrestrial intelligence. There is a small project to develop a fast search system, which can scan in frequency at thousands of times the rate previously possible. This will be a superb radio-astronomy experiment, even if it never finds any signals from little green men. It may survive budget cuts just because it has a very low budget. There are also other initiatives which you probably know about. What do you think about SETI?

FD: Well, I'm very pleased that this effort is finally concentrating on the real technical problem, which is learning how to search a million channels simultaneously. That will enable the radio search to have at least a sporting chance of finding something, which in the past it really never had. And as usual, it turns out to depend on ingenuity much more than on money. So that's great. And I think there's a very good chance that it will go ahead, whether or not the present Administration chooses to fund



DYSON SPHERE: *Artist Rick Sternbach's concept of a "Dyson Sphere"—the signature of a civilization so advanced that it captures the entire energy of its parent star and then radiates the waste heat in the infrared.*

it. It's so cheap, it will be done somewhere in the world.

There are other things which also could be done, particularly in the infrared. This has so far not been pursued with the same attention as the radio search. The problem with the infrared is there's no way in which you can tell immediately that an object is artificial. If you see a radio signal that is coded, with a very narrow band and non-random appearance, it's pretty obviously artificial. There's nothing analogous to that in the infrared, but still there's a great deal to be done there. And I hope that in the next twenty years, it will receive the same sort of attention that the radio search has had up to now.

Radio telescopes do have an enormous advantage. We could already detect the beam of the Arecibo radar with the Arecibo receiver at a distance of a hundred light years, maybe a thousand with some advances. Nothing comparable exists in the infrared. Any large-scale technological activity may nevertheless be seen. By large-scale I mean several orders of magnitude beyond what we are doing at present.

JB: By we, do you mean Earth's civilizations?

FD: Yes. So if there are advanced civilizations at large in the universe and if they are interested in technology at all, they probably have been already technological for millions of years. It's likely they will have expanded far beyond our scale of activities.

JB: And that they will be commanding enormous energy resources. But they still, by thermodynamics, will be rejecting that energy at some temperature. And you're suggesting that it could be in the infrared?

FD: It has to be in the infrared. Really there's not much choice, because of the laws of thermodynamics. If you look at pictures of the Earth taken at night in the infrared band, it is very striking that much of what you see is artificial. So if you want to see what's going on on the Earth in the way of technology, that's the way to look. And if you look at these pictures, you see at once that the economic center of life on Earth is the Persian Gulf.

JB: Flares and flames...?

FD: Yes. Kuwait is the brightest spot on Earth. The same thing would apply, I think, to any form of technology that we know about. It can't help sending out a lot of waste heat, and anything that's compatible with living temperatures, as we know them, has to be infrared.

JB: That's very thought-provoking. We do want to pursue the infrared beyond the first sky survey to be done by the infrared astronomical satellite IRAS. Also, in company with people at the Caltech campus, we are interested in submillimeter radio waves, a part of the spectrum now technologically accessible for the first time.

FD: This is marvelous. I've been trying to propagate the view that one shouldn't distinguish between searching for extraterrestrial intelligence and general exploration of the universe; that the two are really the same thing. If you want to search in an intelligent fashion for intelligent objects, the thing to do is to look in all possible ways at everything, which is the same as doing astronomy. In particular, it's very important to look at the wave bands that have so far not been observed, particularly the submillimeter region.

JB: That is the way the current SETI program at JPL and Ames Research Center is set up. It's trying to get itself sold on the basis that whether or not it sees artificial signals it will do a good radio astronomy job.

FD: That is essential, not only to get money from the government, but also to get support from astronomers. Astronomers by and large are interested in getting results. Their lives are short and they don't have a lot of hours at the telescope. They want to look where interesting things are surely going on. And most astronomers, at least those that I know, are not interested in searching for extraterrestrial intelligence if there's no payoff at the same time in terms of their normal astronomical interests. So the two things have to be combined.

JB: Well, we're doing our best. Is there anything else you'd like to say?

FD: Yes, there is one more thing. As I see it, our place in the scheme of things is to be the midwives, to help life spread out in the universe. It fills me with bewilderment that the universe appears so dead, that everywhere we look we see nothing that we can recognize as alive, except on this planet. Clearly, this is an unnatural state of things. There's no reason why the whole universe shouldn't be the home of life.

JB: Unless one wants to be really pessimistic and say that as soon as life achieves a certain level of sophistication it blows itself up.

FD: But that's not even technically possible. I know there are many ways in which we can come to grief. But as far as I know, there's no way we can really destroy life on this planet, even with the worst possible intentions. Life is remarkably tough. After we were gone, a lot of it would still be here. So, in my view, the purpose of the whole enterprise of pushing out into space is precisely to enable life to make use of all the enormous potentialities that are there.

JB: After you've been through all the other ones, you end up with this question: Why should evolution stop here? I presume that the turtles thought they were the last word....

FD: This problem is going to face us, whether or not we go into space. What is to be our future? Are we an evolving species or not? On the Earth, this problem is really difficult because we have to have a consensus. We're too crowded. We're too strongly interactive with each other. We have to come to a political decision as to whether or not we are going to permit ourselves to evolve further. And it is almost impossible to imagine divisions of opinion not being destructive. I mean, if parts of the Earth wanted to go one way in human evolution and other parts wanted to go another, it would be like the present problem of skin color, only a hundred times worse. Different races with different biological characteristics would want to do different things with themselves. It's hard to imagine how we could cope with that problem. So the natural reaction is that as long as we're here on this planet, we won't allow it. We will say we are brothers; we are going to stay one species; we are going to keep the human faculties as they are. We are happy being human and we won't monkey around with the species.

That is the right solution as long as we are one society on the planet. Most people would feel comfortable with it. But when we go off into space, it's different. The frontier is infinite there. You can go off and get lost. People can go off onto remote places where they are essentially out of contact. Then they are free; they can do as they please. Some of them might like to evolve, and monkey around with their heredity. Nobody is going to stop them. That may be tragic. They may come to grief, as many of them no doubt will. But still, it's something that will be a continuation of the Darwinian process on a larger scale. And it's only when you go off and spread out into a large enough area of the universe so that you are no longer sitting on top of one another, that you can permit yourselves that freedom.

We need to have room for diversity. And diversity is getting harder and harder to achieve on this planet.

JB: We'll try to make some room for diversity with our engineering, provided that we can somehow maintain the social foundation that permits it to go on. Have you any thoughts about what might happen sociologically, anthropologically, historically, that would put us again in the frame of mind that we were in during the heyday of *Apollo*, when we said, 'By golly, if it's doable, we'll do it.'

FD: I don't know. I've lived through this period of technological euphoria in America and I have grown up in England where it happened a hundred years earlier, and heard stories about it from my father and mother. My grandfather was a blacksmith in the North of England in the middle of the nineteenth century, and manufactured machines which were sent all over the world — from just a little village in Yorkshire. Those people had it. Somehow it flourished for fifty years or so and then it declined. It's hard to tell what makes it go and what turns it off. One thing that's true is that in this country things go up faster and come down faster.

JB: Well, let's see if we can get it going up again! Thank you so much for all these good words.

FD: Thank you. □

(continued from page 2)

The stars. Indeed, the stars.

But, of course, dear Sagan reminded me when I wrote the above, that certain migratory birds *do* see and travel by the stars.

A scientific point I chose to gently ignore in order to finish out the poem.

Finally, looking over the long list of authors here and their fascinating, to me anyway, subjects, I am reminded of a more recent encounter at Beckman Auditorium, again with Carl, Bruce, and Walter. I fear I went on at some length when it was my turn, alternately whispering and yelling about the beautiful computers, audio-cassettes, visual discs that will slush in all the bright information, bits and pieces of data, trash, mulch and junk which we must, I insist, absolutely must take on our journey out to the new Olympus we must build and inhabit as minor gods.

In the midst of my jovial outcries, one professor cut in: "What?! Take all that *Trivia!?!"*

To which my response, there and then, and in a poem the next day, went something like this:

Trivia! I cried. But, look!
Great whales survive on trivia.
They gargle sloughs of junk,
They dunk in jeroboams of brit.
So I, with molecules of sifting pollen words
Turn gunk to wit!
From Aardvark A, to D for DeHavilland, Olivia,
Recall the whales, the gray, the white,
Who feed on night and brit, survive,
Thus stay alive...on trivia!

What follows here is *not* trivial. It is central to the philosophy of mankind that started in the caves a long while back and does not end here, but extends on out through time. They express, I express, the informative dreams that have shaped All That's Past, or Passing, or To Come. Which is the title of another of my poems. But aren't you lucky? Here's the end of my Introduction. No more verse. Read on.

A Special Thank You — *We would like to express our appreciation to the artists who contributed their work to this special issue of* The Planetary Report.

MICHAEL CARROLL is a freelance artist and illustrator working in San Diego, California. His work has appeared in Astronomy *magazine and* The Planetary Report. *DON DIXON's first book,* Universe: A Pictorial Atlas, *will be available through Houghton Mifflin in November, 1981. WILLIAM K. HARTMANN is a scientist with The Planetary Science Institute in Tucson, Arizona, as well as a space artist.* The Grand Tour, *a book he is producing with Ron Miller, will be published in the fall by Workman Press. JON LOMBERG is an artist and journalist whose radio documentaries about planetary exploration appear regularly on the Canadian Broadcasting Corporation's program,* Ideas. *RICK STERNBACH is a professional space artist who has worked on numerous books, magazines, motion pictures and television productions. He lives and works in Irvine, California.*

CASSINI'S DIVISION—Arching like a rainbow, Saturn's ring system is one of the most spectacular sights in nature. Seen here from just above Saturn's clouds at 30 degrees north latitude, the sun shines through the Cassini Division of the rings. Wispy clouds of frozen methane, high in Saturn's atmosphere, may refract sunlight to produce prismatic halos.

Don Dixon is a freelance illustrator working out of Irvine, California. He is a frequent contributor to Omni *magazine and has done special effects illustration for NASA. This painting will appear in his first book,* Universe: A Pictorial Atlas, *to be published by Houghton Mifflin in November, 1981.*

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